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GROUND WATER AND POLITICS[a]

by Dr. Jay H. Lehr
Executive Director,
NWWA

If we are yet to save the last frontier of our nation's water supplies, the ground-water hydrologist and geologist, engineer, consultant and planner must come out of his tower or closet and enter the political arena and make himself or herself heard. In 1972, a new Water Pollution Control Act was passed after two years of heated controversy—controversy which rarely touched on ground water—the latter topic having been easily disposed of by a powerful oil and gas lobby.

With the handwriting clearly on the wall regarding the congressional disinterest in ground-water protection, NWWA attempted an end run by jumping into the middle of the drinking-water legislation just in its embryonic stages in 1971 through efforts by Congressmen Howard Robison of New York and Paul Rogers of Florida. Rogers emerged as the main spokesman for the legislation through his inherent power as Chairman of the House Subcommittee on Public Health and Environment of the Interstate and Foreign Commerce Committee.

NWWA educated Rogers early in the game that as over 50 percent of drinking water today comes from underground-water supplies, no Safe Drinking Water Act will be effective without providing ground-water protection presently missing from the Water Pollution Control Act.

Throughout the past three years ground-water protection language has alternately expanded and contracted within the proposed legislation as various negative interests rose and fell in committee favor. The oil industry was caught sleeping in 1971 and 1972 on this legislative activity because they were so busy on the WPCA, but in 1973 they began to fight waste disposal regulations in the Safe Drinking Water Act. Their efforts, coupled with the desire of Congress to protect State rights and their objection to the expense of controlling ground-water pollution have continued to obstruct adequate ground-water protection language.

Three years and ten congressional appearances later by NWWA, the cause of ground water is still in doubt but very much alive.

This audience could be the strongest force yet mounted. Any indication to your congressional representatives by you and your

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[a] Delivered as the Keynote Address at the Second [illegible]ional Ground Water Quality Symposium, Denver, Colorado, September 25, 1974.

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colleagues will strongly advance the cause in what has been a veritable vacuum of activity on the part of our fellow scientists, with the exception of NWWA whose singular presence without adequate grass roots scientific support is lonesome indeed.

The time to act in getting the attention of Congress is now. If we still lose we will at least have laid the ground work for a future, more successful effort to convince each State to protect its precious ground water so as to retain its optimum potential benefits.

I have long been dismayed by the lack of necessary dedication amongst our scientific fraternity of ground-water people to work together in a common cause. Obviously those I address here are not those I wish to reach. Your presence here indicates you care enough. Six hundred other ground-water scientists belonging to the National Water Well Association did not and are not here. But five will get you ten they attended some other national meeting this year. The Technical Division of NWWA must get it together as it has never done before.

We must not allow our goals to be splintered. The AGU has a Ground Water Committee. GSA has some activity, as does AWRA. But if you really want action, the action will best come through NWWA. United we stand, divided we fall. On this issue I must express some remorse at the decision of some State ground-water officials to form the National Association of State Ground-Water Officials outside of the NWWA Technical Division when it may well have become an active, effective and well supported arm of the NWWA Technical Division.

Ground water is invisible enough as it is. I think that the more collective our effort, the greater our hope for visibility without the aid of a microscope.

In this Second National Ground Water Quality Symposium, let us not only talk of technological advantages of the laboratory type, but let us also deal with the administration problems of bringing our ideas to fruition. It is not enough to know how something should be done, we must determine how to *get* it done.

In the past decade we have seen successful revolutions for many minority groups. May this Symposium signal the beginning of a truly organized ground-water development and protection revolution whose success can be celebrated when we meet again two years hence for the Third National Ground Water Quality Symposium in Las Vegas, Nevada, on September 15-17, 1976.

C. L. McGuinness — Hydrogeologist, Writer, Teacher[a]

by Gerald Meyer[b]

In the moments available to me I should like to highlight Mac McGuinness' contributions to water understanding, not for documentation of his awesome array of significant writings, but in the perspective of the continuing significance of this gifted man's works to water problems, and the important benefits of other legacies not generally known.

The directions set by Mac's (many called him Lee) latest writings suggest that his untimely death, April 25, 1971, probably cut short a bonanza of new insights and ideas directed to water issues. He was acutely aware of the social and economic worth of accumulated knowledge and understanding of ground water, and his most recent works seemed bent on insuring public awareness of the applications of that body of knowledge, and on bringing the physical sciences and the social sciences into comfortable acquaintance. In the parlance of today, he was "getting involved"—employing his most proficient tools, his mind and pen—and I wish he had been given more time.

Thoughtful browsing through his career record—a remarkably varied one, including proficiency in photography and camera repair, firearms and shooting, remote sensing, electronics, water law, soils science, writing, editing and review, and, of course, his beloved hydrogeology—one is attracted especially to his writings and his mastery of clear scientific expression. As Chief of the Technical Reports Section of the Geological Survey's Ground Water Branch for 15 years, he set a personal example of technical excellence and writing clarity, exercising his manuscript-review responsibilities with powerful influence on the scientific and editorial quality of reports of the Branch personnel and on technical betterment of the authors.

Through the broad affiliations of the Geological Survey with Federal and State agencies and universities in the U.S.A., and with many Nations of the world, his impacts on literary and technical standards in ground-water hydrology were extended worldwide. He was, in his own way, a teacher. He taught with his pen.

Hearing himself labelled a teacher, Mac would have elevated his big, bushy eyebrows in surprise, following perhaps with a hearty chuckle of disbelief and denial. But, if a teacher is one who encourages, shapes, nudges, cajoles, leads, and upgrades the thoughts of others, then Mac was indeed an unusually gifted teacher. In 1950, he was drafted to assist the President's Water Resources Policy Commission on evaluation of the Nation's ground water and related water laws, followed by similar service to the Senate Select Committee on National Water Resources. Subsequently, taking advantage of materials prepared for these assignments and isolating himself from interruptions, he fell to writing "The Role of Ground Water in the National Water Situation" (McGuinness, 1963), a comprehensive analysis of the Nation's ground-water resources which won him international note and a number of awards, including the O. E. Meinzer Award of the Geological Society of America. Aided by contributions from each of the Geological Survey's district offices, its 1,121 pages reflect the phenomenal scope of the author's knowledge and his intense devotion to the communication of hydrologic facts and to clarity of expression. Issued in 1963 as Geological Survey Water-Supply Paper 1800, there exists no other summation of the Nation's ground water to equal it. Demand for the report continues 11 years after its first printing, attesting to its continuing pertinency.

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[a] Memorial address presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

[b] Chief, Ground Water Branch, U.S. Geological Survey, Reston, Virginia 22092.

Contrasting in size, but equally impressive on its own merit, is a simple 26-page booklet co-authored by Mac with Helene L. Baldwin (1963), which I commend to all who find it necessary to traffic in ground water but may lack knowledge of its fundamentals. Entitled "A Primer on Ground Water," this modest document serves up the rudiments of the science, the resource, and management principles for quantity and quality in simple lay language and graphics. In print it looks deceptively easy, but anyone who has had to communicate technical facts to the uninitiated will admire the writing craftmanship demanded by this readable and instructive lay document. In the present era of increasing interplay among scientific disciplines and increasing dialogue with workers in nonscientific fields, it is all the more extremely valuable as teaching material and an introduction to ground water.

Between these two extremes in style and content, lie a great assortment of writings. I am especially fascinated with Mac's most recent works reflecting a watchful assessment of new technical movements in the ground-water discipline, and the broadening interrelations of ground-water hydrology with the social and economic fields. His papers carrying titles such as "The Changing Role of Ground Water in Our Society" (1967), "New Thrusts in Ground Water" (1969a), and "Scientific or Rule-of-Thumb Techniques of Ground-Water Management" (1969b), reveal a leaning to the philosophical, and one must wonder where his pen would have led him if he had been granted more time. Here is what Mac had to say in 1969 about the burgeoning demands on hydrogeology at the midpoint of his five years of service as Chief of the Ground Water Branch, U.S. Geological Survey:

> "Of all the things that might be said about ground water in today's world, one that seems highly appropriate to me is an expression of amazement. After years—in fact, decades—in which students of ground water felt that we were just voices crying in the wilderness, the world has suddenly discovered our subject. Now we don't know whether to laugh or cry, because the world suddenly wants from us more than we have to give—more knowledge than was ever demanded before, and more than we ever dreamed would be needed" (McGuinness, 1969a).

Mac's paper on scientific versus rule-of-thumb techniques was written for the 23rd International Geological Congress in Prague in August 1968. It reveals his comfortable comprehension of the functioning of ground-water systems, including chemical and biologic relationships, and his philosophical insight into the unfolding role of modeling. He petitioned for enlarged support of new research to insure competent techniques "for predicting aquifer response to imposed forces, whether static, hydraulic, thermal, or chemical." These methods, he felt, are preferable by far to management of aquifers by rule-or-thumb standards. Presentation of the paper was aborted by the Russian occupation of Prague, with Mac scurrying out of Czechoslovakia by rail. (One should not construe that the contents of Mac's paper precipitated the surprise invasion.)

Mac was continually involved in important ground-water issues, usually behind the scenes and hidden from public awareness, but nonetheless having significant impact on the interests of ground-water hydrology and the water industries. He served as the Geological Survey representative to the Public Health Service's Advisory Committee for State Legislation on Planning of Urban Water Supply and Sewage Systems, seeking with the National Water Well Association, Water Systems Council, and others to see that ground water got a fair hearing and a fair shake at the hearings. (And, through these joint efforts, it did.) He was the Interior Department representrative on a work group, assigned to the Office of Science and Technology, to assist a task group on coordination of water research in the Federal Government. These actions were instrumental in establishment of the Committee on Water Resources Research, the only coordinating body for water research in the Federal structure. Additionally, early in the inception of the Interior's Office of Water Resources Research, he helped design and install procedures for processing applications for research funds received from the newly emerging water-resources institutes at universities and colleges.

Some further involvements: If you seek out an explanation of a ground-water term in the latest edition of the American Geological Institute's Glossary of Geology (Gary, McAfee, and Wolf, 1972), it is an explanation furnished by Mac McGuinness. If you utilize a copy of the Geological Survey's "Suggestions to Authors" (U.S. Geological Survey, 1958), the basic reference of style, form, and expression in Survey technical reports, you may recognize Mac's fine touch. And, if you have occasion to refer to Water-Supply Paper 1988, "Definitions of Selected Ground-Water Terms—Revisions and Conceptual Refinements" (Lohman and others 1972), an analysis of the concepts behind common fundamental ground-water terms, here too you will encounter Mac's handiwork.

By these examples you see that Mac McGuinness was indeed "involved," both behind the scenes in effective ways not readily evident, and more prominently through his publications. For more information on this talented man and his legacies to the ground-water community, I would refer you to the two memorial papers listed in the References, one by Stanley W. Lohman (1971) and the other by George V. Cohee (1971), both of which were used freely in the preparation of this paper. Lohman's paper includes a complete bibliography of Mac's publications.

I might close with another bit of Mac's pragmatic philosophical advice, which is addressed to those of us who wrestle daily with the Nation's water problems. Encouraging accelerated pursuit of improved analytic and management tools for ground water, and collection of reliable and pertinent supporting hydrogeologic data, he observed (McGuinness, 1969a): "The more we do, the bigger the remaining job seems. But it would be still bigger if we did nothing, so we might as well get at it."

I am sure Mac McGuinness would have agreed that this series of symposia on the Nation's ground-water quality is certainly one highly effective way of "getting at it." Mrs. Helen Louise McGuinness and I are extremely pleased to have been invited to the Proceedings.

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New Priorities for Ground-Water Quality Protection[a]

by David W. Miller[b] and Marion R. Scalf[c]

ABSTRACT

Four regional studies of the status of ground-water pollution problems in 26 States have been sponsored by the U.S. Environmental Protection Agency. These investigations involved comprehensive reviews of the literature and contacts with public officials and others involved in water supply, so that individual case histories of ground-water contamination problems could be evaluated. Septic tanks and cesspools, petroleum exploration and development, landfills, irrigation return flows, and surface discharges, impoundments, and spills are the principal sources leading to degradation of ground-water quality.

Only a very small percentage of the instances of ground-water contamination that probably exist has been discovered to date, and almost all the reported cases were only discovered after a water-supply source had been noticeably affected by one or more pollutants. In the vast majority of cases inventoried, the problem has not been corrected and will become more troublesome in the future. A prime need in all four regions is a greater effort toward locating and evaluating as many additional cases of ground-water contamination as possible.

Over the past four years, the U.S. Environmental Protection Agency, through the Robert S. Kerr Environmental Research Laboratory in Ada, Oklahoma, has been sponsoring an evaluation of the key ground-water pollution problems throughout the nation. To date, four regional investigations have been carried out, and they include a total of 26 States in the northeast, northwest, south-central, and southwest portions of the country. Table 1 lists the States covered in each of the regions. The findings of these studies have been used to establish priorities for research into ways to correct existing sources of contamination and to point out deficiencies in present control methods for protecting against further degradation of ground-water quality.

Table 1. States Included in Each of Four Project Regions

Northeast	*Northwest*	*South Central*	*Southwest*
Connecticut	Colorado	Arkansas	Arizona
Delaware	Idaho	Louisiana	California
Maine	Montana	New Mexico	Nevada
Maryland	Oregon	Oklahoma	Utah
Massachusetts	Washington	Texas	
New Hampshire	Wyoming		
New Jersey			
New York			
Pennsylvania			
Rhode Island			
Vermont			

Without a thorough understanding of which activities of man are having the greatest impact on ground-water quality, effective programs for long-term protection of this resource cannot be developed. For years, salt-water intrusion, septic tanks, irrigation return flows, and industrial waste injection wells have been the principal concerns of regulatory agency personnel and investigators in the ground-water field. However, even though these are important sources, more attention must be paid in the future to the tens of thousands of surface impoundments, landfills, buried pipelines and storage tanks, abandoned oil, gas, and water wells, and uncontrolled surface discharges that are adding millions of gallons of contaminated water each day to the ground-water system.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

[b] Vice President, Geraghty & Miller, Inc., Consulting Ground-Water Geologists, 44 Sintsink Drive East, Port Washington, New York 11050.

[c] Sanitary Engineer, Subsurface Environment Branch, Robert S. Kerr Environmental Research Laboratory, Ada, Oklahoma 74820.

Some of the key conclusions obtained from the various regional studies of ground-water contamination problems are as follows:

1. Only a very small percentage of the instances of ground-water contamination from all sources that probably exist in each of the regions has been discovered to date. Almost all of the reported cases were only discovered after a water-supply well or spring had been noticeably affected or the pollutant was being discharged to the surface. Few cases of ground-water pollution are uncovered as the result of specific studies, such as those directed toward investigations of salt-water intrusion in coastal areas, or as the result of specific monitoring of potential sources of contamination. Such monitoring is almost non-existent in all four regions.

2. In the vast majority of cases inventoried, the problem of ground-water contamination has not been corrected from either the standpoint of removing the source of contamination or significantly improving the quality of the affected ground-water supply. The principal reasons for the lack of success in dealing with existing ground-water contamination problems are deficiencies in the technology presently available to satisfy economic, social, and political restraints; inadequate budgeting and staffing together with the diverse interests of regulatory agencies; and a general lack of understanding in each region as to how the various activities of man can degrade ground-water quality.

It should be kept in mind that the normal range of cost to investigate ground-water contamination problems involving landfills and industrial waste lagoons is $20,000 to $100,000. This includes test drilling to define the areal extent of the contaminated ground-water body, water quality analyses to determine the character of the pollutant, consultant fees, and litigation expenses. Estimates for solution of landfill and industrial waste lagoon problems, including procedures for eliminating the source of pollution and to contain or remove the pollutants already in the ground, range in the millions of dollars. Some problems, such as widespread contamination of an aquifer with septic tank effluent or oilfield brines, are insoluble at almost any cost.

The inclusion of ground water in new laws and regulations as one of the resources to be protected when dealing with activities that might degrade the environment is a relatively new development. However, even at this late date, progress along these lines is slow and is hampered by the complexity of creating workable legal guidelines.

3. There are two basic approaches that have been used to clean up contaminated ground water. The first is containment and the second is actual removal of the pollutant. Containment involves the use of methods to protect against the spread of degradation of water quality within the aquifer already contaminated, to other aquifers that may be affected, or to surface-water bodies into which the contaminated ground water might discharge. These methods include removing the source of contamination, for example lining a waste-water lagoon, or creating barriers against movement of the pollutant by means of pumping wells.

Actual removal of the pollutants from the ground-water reservoir has been attempted at a few locations, especially where hazardous wastes are involved. Use of wells drilled specifically for the purpose of pumping out the contaminated fluid is the most common approach, but existing water-supply wells have been used, in addition to surface drains and ditches.

4. Existing ground-water contamination problems will become more troublesome in the future because of the long-time factors involved in decay of the pollutants, the slow movement of the affected ground-water body, exhaustion of the soils' ability to reduce the concentrations of or to remove specific pollutants, and the ever-increasing volume and complexity of contaminating fluids. Practices leading to pollution have been most active over the past 30 to 40 years, which is a relatively short time period with regard to the migration of pollutants in the ground. Most pollutants are still in water-table aquifers and within close proximity of their source. With time, contamination will spread horizontally and vertically and affect more and more surface streams and water-supply wells.

Throughout this paper, the terms "pollution" and "contamination" are synonymous and mean the degradation of natural water quality, as a result of man's activities, to the extent that its usefulness is impaired. There is no implication of any specific limits (such as those in the U.S. Public Health Service drinking water standards), since the degree of permissible pollution depends upon the intended end use, or uses, of the water. Increases in concentration of one or more constituents as the natural result of movement of ground water through an aquifer are referred to as "mineralization."

DESCRIPTIONS OF PROJECT REGIONS

Northeast

The northeast study region covers over 190,000 square miles, which is approximately 6 percent of the conterminous United States. Characteristic physiographic features range from broad areas of minor relief in the southeastern portion to hilly and rugged, mountainous terrain in the west and north. As of the 1970 census, 53.5 million people or over 26 percent of the nation's population resided here, heavily concentrated in the Boston to Washington, D.C., megalopolis. Climate of the region is humid, with average annual rates of precipitation ranging from 32 to 50 inches. In 1970, 18 percent of the total water used in the area was from ground-water sources. The largest use of ground water was for public supply.

Natural ground-water quality in the Northeast is suitable for most purposes with little or no treatment. High iron content (with associated high concentrations of manganese), low pH, and sometimes high hardness are the most widespread problems. High total dissolved solids and chlorides are characteristic of ground water in some coastal aquifers and in deeper bedrock units underlying western Maryland, New York, and Pennsylvania.

Northwest

The northwest study region covers an area of 600,000 square miles, representing 20 percent of the conterminous United States. The region is characterized by a wide variety of landform features, ranging from plains, large basins and lowlands, to intermontane plateaus and high mountains.

Climatic conditions differ widely because of the varied topography and movement of air masses across the continent. The Pacific zone has a coastal-marine climate with high precipitation and runoff and low evaporation rates. Eastward, the climate becomes the high-desert type with low precipitation, low runoff, and high evaporation rates.

In 1970, approximately 9.5 million people, or nearly 5 percent of the total United States population, resided in the project area. Ground water provided 12 percent of the total water used, with irrigation the largest user of both ground and surface water.

In the Pacific Coast States, ground water is comparatively low in total dissolved solids, but high in iron and manganese. Ground water in many areas of Montana, Wyoming, and Colorado contain high concentrations of fluoride. In addition, there are numerous thermal springs and large areas are underlain by aquifers yielding ground water with a high total dissolved solids content.

South Central

The south central study area covers 560,000 square miles, or about 19 percent of the conterminous United States. The region is characterized by high mountain ranges, vast stretches of deserts and plains, and large swamps.

Climate varies from arid, in the deserts of New Mexico and west Texas, to humid in the marshlands of Louisiana, with annual precipitation of 8 and 64 inches, respectively.

In 1970, there were 20 million residents, representing 10 percent of the United States population. Ground water provided 57 percent of the total fresh water used in 1970, with the largest withdrawals for irrigation. Natural ground-water quality ranges from generally good but hard, to very hard with high concentrations of iron, fluoride, or sulfate. Several areas are troubled by arsenic, dissolved gases or objectionable amounts of silica or nitrate.

Southwest

The southwest study area covers 468,000 square miles, about 13 percent of the conterminous United States. Characteristic physiographic features include high mountain ranges, vast deserts, several large salt lakes, and the Colorado plateau. Climate for the most part is arid to semi-arid (less than 10 inches annual precipitation over broad areas). However, some of the mountains in California and Utah have relatively high precipitation, and several locations within the north coastal basin of California receive over 80 inches.

In 1970, the population of the area was over 23 million people. Ground water supplies about one-half of the total fresh-water requirements of the region with irrigation the largest consumer.

Natural ground-water quality is generally good. However, high concentrations of total dissolved solids and chloride are encountered in some coastal areas of California and some inland regions of the other States. There are also scattered areas of excessive fluoride, boron, iron, nitrate, and manganese.

SOURCES OF CONTAMINATION

Each of the investigations of ground-water contamination problems involved a thorough review of the literature of the region. However, few descriptions of known instances of contamination have been published. In order to gain a more accurate perspective on the status of pollution, it was necessary to contact public officials, consultants, scientists, well drilling contractors, representatives of industry, and others involved in water supplies so that their files and individual experiences could be applied to the various studies. In the Northeast alone, information was obtained on more than 1,000 cases of ground-water contamination. The results of each of the investigations have been published in a report, except for the Northwest which is still in preparation (van der Leeden *et al.*, 1974).

A brief discussion of the findings for each of the significant sources of contamination follows. Their relative importance by region is given in Table 2. The four pollutants most commonly reported and the source of contamination are given in Table 3.

Septic Tanks and Cesspools

By sheer volume of waste water discharged, septic tanks and cesspools must be rated as the key potential source of ground-water contamination in all four regions. In the 11 States covered by the northeast study, approximately 12 million people are served by individual home waste-water treatment systems. Assuming an average domestic water use of 40 to 80 gallons per day per capita, as much as one half to one billion gallons of raw sewage is discharged from residences directly into the subsurface each day. To this figure must be added the millions of gallons per day discharged to the ground from commercial and industrial septic tanks.

It is a generally accepted fact that as much as 300 milligrams per liter of total dissolved solids are added to water by domestic use, and thus, the effluent from septic tanks can increase the concentration of minerals in ground water. The major concern or indicator of pollution from septic-tank and cesspool effluent is nitrate. Bacteria and viruses are normally removed by the soil system, but under conditions favorable for their survival, can reach the water table and can travel significant distances through an aquifer.

Of growing concern is the tremendous increase in the number of homesites where soil and geologic conditions are not favorable for sufficient removal of pollutants. This condition exists in many mountainous resort areas. Arid regions are especially vulnerable to contamination of ground-water supplies where homes are served by both on-site wells and waste-disposal systems. Because of the lack of

Table 2. Principal Sources of Ground-Water Contamination and Their Relative Importance by Region

	Northeast	*Northwest*	*South Central*	*Southwest*
Septic Tanks and Cesspools	I	I	I	I
Petroleum Exploration and Development	II	II	I	I
Landfills	I	II	II	II
Irrigation Return Flows	IV	I	I	I
Surface Discharges	II	I	III	I
Surface Impoundments	I	I	II	III
Spills	I	II	II	II
Buried Pipelines and Storage Tanks	I	II	II	III
Mining Activities	II	I	III	II
Salt-Water Intrusion				
Coastal Areas	III	III	II	I
Inland Areas	I	II	II	II
Water Wells	II	III	I	III
Agricultural Activities				
Fertilizers	III	II	III	II
Feedlot and Barnyard Wastes	III	III	II	III
Pesticides	III	III	III	III
Disposal Wells				
Deep Wells	IV	III	III	III
Shallow Wells	II	I	III	III
Highway Deicing Salts	I	III	IV	IV
Artificial Recharge	III	IV	III	II
River Infiltration	II	II	IV	IV
Spray Irrigation by Waste Water	III	IV	III	III

I – High
II – Moderate
III – Low
IV – Not significant

Table 3. The Four Pollutants Most Commonly Reported and Source of Contamination

Source	*Chlorides*	*Nitrates*	*Hydrocarbons*	*Heavy Metals*
Septic Tanks and Cesspools	x	x		
Petroleum Exploration and Development	x		x	
Landfills	x			x
Irrigation Return Flows	x	x		
Surface Discharges	x	x	x	x
Surface Impoundments	x	x	x	x
Spills	x		x	x
Buried Pipelines and Storage Tanks		x	x	x
Mining Activities				x
Salt-Water Intrusion	x			
Water Wells	x	x		
Agricultural Activities		x		x
Disposal Wells	x	x		x
Highway Deicing Salts	x			
Artificial Recharge	x	x		
River Infiltration	x			x
Spray Irrigation by Waste Water	x	x		

natural recharge and dilution, recirculation of waste water can be an important factor in pollution over the long term. Even in humid regions, investigators have concluded that the relatively small amount of natural ground-water recharge available in areas underlain by poor aquifers limits septic tank use. Studies have shown that in many housing developments recycling of liquid waste in the ground-water system is an inevitable fact of life.

Probably the most comprehensive field research on the effects on ground-water quality of effluent discharged by typical individual sewage disposal systems has been carried out on Long Island, New York. Contamination from septic tank and cesspool effluent, and to some degree from fertilizers, has occurred in major aquifers over an 180 square-mile area. The nitrate-enriched water has penetrated hundreds of feet into the principal artesian coastal-plain aquifer.

In spite of their potential for ground-water contamination, millions of septic tanks will continue to be used in all of the regions studied, and their over-all numbers will probably increase during at least the next decade. Limitations on local, State, and Federal budgets limit the installation of public sewers. Even in areas where the density of housing and problems of ground-water contamination have justified the need for conversion to collecting sewers and treatment plants, a long time period is normally required for the public systems to become fully operational after funding has been secured.

Petroleum Exploration and Development

In 1969, 70 percent of the total United States crude oil was produced from more than 300,000 wells in the south central region. Each operating oil or gas well is considered a potential or actual source of pollution to fresh-water aquifers because of improper control of gas, oil, salt water, or the many chemicals used in drilling and production activities. Production of crude oil is usually accompanied by the production of waste water of variable but usually high chloride content. A ratio of a dozen or more barrels of brine to each barrel of oil produced is not uncommon, and billions of barrels of brine waste water are produced in the south central States alone each year.

Most oil field brines are returned to subsurface formations through old production wells or brine disposal wells for the purpose of waterflooding or just as a disposal method. However, many of these wells are poorly designed for injection, and they offer the opportunity for the salt water to enter fresh-water formations through ruptured or corroded casings.

Abandoned oil and gas wells, in addition to test holes drilled for geophysical exploration, are also potential sources of ground-water pollution. Open bore holes or abandoned wells with corroded casings can act as conduits for surface pollutants to enter the ground-water reservoir. Some improperly plugged wells discharge brine continuously on the surface, contaminating shallow fresh-water aquifers. Even in cases where the well is not flowing, saline water from deep formations can migrate under natural pressure up the bore hole and enter shallow aquifers containing potable water.

Another problem has been the widespread practice of discharging the brine waste water to unlined pits and basins. The highly mineralized water can leak into shallow aquifers over broad areas. Spills and leaks from pipes and tanks are also common in oil fields.

Similar conditions to those described above for the south central region also exist in each of the other three regions. Although many States have passed legislation and are enforcing regulations on lining brine pits, plugging abandoned wells, and otherwise controlling pollution from petroleum exploration and development, the problem is so extensive that this source of ground-water contamination will be an important one for many years to come. The problem has not been adequately studied in any of the four regions. Brine contamination of ground water from pits and wells is only now being discovered in areas where oil and gas production was abandoned 30 or more years ago. In many places where ground-water contamination has occurred, records simply are not available of where abandoned oil and gas wells are located.

Landfills

Cases of contaminated ground-water supplies caused by the leaching of solid wastes contained in municipal and industrial landfills has been reported in each of the four regions studied. The problem has been most severe in the heavily urbanized area of the Northeast where an annual average precipitation of 42 inches can result in the generation of 57 million gallons of leachate per year at a 100-acre landfill site.

The principal indicators of pollution identified in the documented cases of ground-water contamination related to municipal solid waste disposal include high concentrations of BOD, COD, total dissolved solids, hardness, iron, sulfate, and chloride. For industrial landfills, a number of instances of ground water being contaminated with heavy metals and various organic compounds have been reported. For example, in one case in the Northeast, ground water containing up to 18 mg/l of lead has traveled at least 500 feet from an industrial landfill site through coastal plain deposits toward a nearby municipal well field. In the Northwest, landfilled sawdust containing glue extracts has caused phenols to enter a shallow aquifer, resulting in contamination of nearby domestic wells.

The polluted ground-water body in many instances is confined to within the general property boundaries of the landfill site. However, there were cases inventoried in the Northeast where pollutants were detected in significant concentrations after migrating more than 1,000 feet. In several instances, contamination could be traced a distance of more than a mile from the source.

Data obtained on landfill contamination of ground water in the Northeast indicate that the thousands of landfills in the region containing municipal and industrial solid waste are an almost universal source of pollution. For the south central States, it has been concluded that the major solid waste threat to ground-water quality is probably from land disposal of industrial wastes, which can consist of highly complex substances.

With the trend toward greater use of monitoring wells by public agencies, it is reasonable to forecast a rapid increase in the discovery of new problems at existing landfills. Unfortunately, adequate alternatives for eliminating existing landfills as a continuing source of contamination have not been developed. On the other hand, the siting, design, and operation of new landfills is receiving increased attention and regulation, which should help in limiting the development of future problems.

Irrigation Return Flow

Irrigation return flow is water diverted for irrigation purposes that finds its way back into an existing or potential water supply. This process concentrates salts by evapotranspiration and can introduce chlorides and other substances from irrigated lands into a ground-water aquifer by means of infiltration. Pollutants in irrigation return flows may originate from many sources including the applied water, soils, fertilizers, and pesticides.

In all but the northeast region, irrigation return flow is considered a major problem which has led to a large number of areally extensive ground-water contamination cases. In the south central States, for example, ground-water quality has deteriorated from irrigation return flows in the Rio Grande basin of New Mexico and Texas. Other problem areas include the Pecos River valley in New Mexico and Texas and the Arkansas River valley in Oklahoma and Arkansas. In the southwestern States, degradation of ground-water quality on a broad scale has been reported in the San Joaquin basin in California.

In the northwestern States, it is estimated that there are over two million acres of saline land within the region. A few of the larger areas currently experiencing irrigation return flow problems are: the valleys of the Grande, Platte, and Arkansas Rivers in Colorado; the Yakima valley in Washington; Larimer County in Wyoming; Rosebud County in Montana; the Snake River valley in Idaho; and the lower Columbia River basin in Washington. One of the severest and best studied instances of a problem related to irrigation return flow is in the Grande Valley of Colorado, where a high percentage of the irrigated acreage has become marginal because of a high water table and concentrated salts. It has been estimated that approximately 37 percent of the total salt load from the Upper Colorado Basin is associated with irrigation return flows in this area.

Irrigation return flows from agricultural practices are and will continue to be a major source of ground-water contamination within the foreseeable future. In some areas, the problem could decrease in severity as new techniques are developed for application and management of irrigation waters and more efficient use is made of crop types.

Surface Discharges

Discharge of effluent from sewage treatment plants to dry stream beds and intermittent disposal of wastes on the open ground at industrial and commercial facilities are important sources of ground-water contamination. In the northwest region, discharge from sewage treatment plants has created widespread problems of ground-water quality degradation in the Denver, Colorado area. Effluent released to stream channels has infiltrated valley fill aquifers contributing to high detergent and nitrate levels in ground water. Similar problems have occurred in some of the arid basins of the Southwest.

In the northeast region, one case of ground-water pollution, with arsenic concentrations exceeding 10,000 mg/l, was discovered at an industrial site and traced to long-term discharge of waste water to the land surface. In a recent study on the disposal and management of waste oil in 18 counties of the New York metropolitan region, it was determined that millions of gallons per year of used auto lube and crankcase oil are simply dumped on the ground by individuals and gasoline station owners.

More attention must be given to uncontrolled surface discharges of liquids that can create problems of ground-water contamination. Regulatory agencies have halted uncontrolled discharge of wastes to the land surface where such practices have come to their attention and where there is an alternative available. Frequently, by the time the magnitude of the problem is properly appreciated, pollution is so widespread that clean-up operations are neither economically nor technically feasible.

Surface Impoundments

Surface impoundments used for storage and treatment of liquid municipal and industrial wastes are serious threats to ground-water quality. Some impoundments containing waste effluent from sewage and industrial plants are referred to as "evaporation" ponds, but actually only operate successfully if seepage of the liquid wastes to the subsurface occurs.

Statistics on the number and location of surface impoundments that may be a potential threat to ground-water quality have never been compiled. However, in one State in the Northeast, an inventory was conducted by means of low-level aerial survey flights. It was estimated that more than 1,500 industrial waste impoundments exist in the area inventoried and that each one is a potential source of ground-water contamination. In the south central region, thousands of sewage lagoons are scattered throughout the five-State area and undoubtedly contribute much to the pollution of ground water. Relatively high concentrations of nitrates have been found in shallow aquifers underlying many of these sewage lagoons.

In the cases of ground-water contamination inventoried in the Northeast, the most important pollutants found in the ground water associated with leaky lagoons and other types of surface impoundments include heavy metals such as chromium, cadmium, and mercury; phenols; and various forms of hydrocarbons. The largest number of instances are those in which the surface impoundments were receiving wastes from chemical and metal processing industries.

The plumes of contaminated ground water developed as a result of leakage out of surface impoundments can be extensive in size and may contain large volumes of polluted ground water. In one case in the Northwest, disposal of liquid chemical wastes into unlined holding ponds has caused pollution of shallow ground water over an area of 12 square miles. In the Northeast, disposal of liquid wastes from a metal processing plant into unlined basins, covering an area whose total size is less than an acre, created a plume of contaminated ground water 4,300 feet long, 1,000 feet wide, and 70 feet thick during a period of about 13 years. The maximum volume of contaminated ground water contained within this plume was estimated at 200 million gallons.

Few of the surface impoundments that may be contributing to ground-water contamination have ever been monitored to determine their effect on ground-water quality. If such monitoring were to take place, it is quite probable that a substantial number of additional problems would be discovered. Unfortunately, removal of the pollutants from the ground normally is not economically feasible.

Because there have been some serious instances of ground-water contamination already reported, public agencies in the four regions are putting into effect more stringent controls over the manner in which new surface impoundments are constructed and the type of wastes that can be stored. Typical regulations call for lining lagoons and basins with a material of low permeability where the impoundment is receiving untreated or hazardous wastes.

Spills

Accidental spills of liquid wastes, toxic fluids, gasoline, and oil occur in every region, accompanied by the risk that the pollutant can migrate down to the saturated sediments in the vicinity of the spill, and degrade ground-water quality. Spills can occur at industrial sites, along highway and railroad rights of way, and at airports. By far the most prevalent pollutants reported as affecting ground-water quality from this source are hydrocarbons.

A typical instance of a serious case of ground-water contamination from a spill occurred in the Northeast in 1957 when 30,000 gallons of jet fuel were spilled on the ground at an Air Force base. The crystalline rock aquifer was so badly polluted that the original wells supplying the base could not be used for 15 years after the spill took place. In the Northwest, the Department of Ecology of the State of Washington recorded, during the first six months of 1973, nearly 500 complaints of spills, some of which affected ground-water quality.

The accidental spill is an unavoidable hazard inherent in the storing and transportation of fluids. It is in the handling of spills after they have taken place that better protection of ground-water resources can be achieved. In the past, for example, liquids spilled on highways have been simply flushed from the road to adjacent soils at the expense of pollution of a shallow aquifer in order to have a minimal effect on traffic flow. Because time appears to be the most important factor in minimizing ground-water pollution from spills, some States, including Pennsylvania and New Jersey, have developed procedures for reporting spills to the proper authorities so that effective action can be taken quickly.

Buried Pipelines and Storage Tanks

Pollutants escaping from leaky and ruptured buried pipes, including sewers, and from storage tanks have affected ground-water quality at a number of locations in all four regions. The principal pollutants reported are hydrocarbons, which have leaked from gasoline service station and home fuel-oil storage tanks, industrial production facilities, and petroleum product transmission lines.

Details on the number of cases of ground-water contamination due to leakage from buried tanks and pipelines that occur in the various regions each year are not available. However, some statistics are revealing. In the northeast region, the Pennsylvania Department of Environmental Resources estimates that 2,600 new or replacement storage tanks are buried each year within that State. Failure of the tank is normally the reason for replacement, and the product originally contained has been lost to the ground. In the northwest region, the Colorado State Oil and Gas Inspection Office records gasoline leaks on a monthly basis. As much as 37,000 gallons from various sources leaked into the subsurface during one 30-day period. One interesting study in Colorado indicates that salts used for deicing service station driveways and electrolysis from electric street cars has increased corrosion in buried steel gasoline station tanks, leading to a greater incidence of failure.

A well documented case in the southwest region is that which occurred in southern California in 1968. Thousands of gallons of gasoline were found to have contaminated a broad area underlying the City of Glendale. About 30 wells for observation, containment, and removal were drilled in the problem area. The clean-up operation also involved installation of two special facilities for separating gasoline from the polluted water pumped from the wells.

Exfiltration and infiltration occurring in sanitary and storm sewers is a recognized engineering phenomenon. Where the system originally was designed poorly and installed improperly, or where the pipelines are old and in disrepair, leakage of substantial quantities of poor-quality water into the soil system can take place, eventually leading to contamination of an aquifer. In Kings County, Long Island, New York, leakage from sewers may be the principal source of nitrate and total nitrogen in the ground water. In fact, leakage is so great that sewage is a significant source of artificial recharge in this heavily urbanized area.

Leaks in buried tanks and pipelines are a continuing problem that is coming under greater scrutiny by public agencies in all four regions. However, programs directed toward protection of ground-water quality have not yet been developed to any significant degree. Research on methods for removing hydrocarbons from the ground-water reservoir is greatly needed because attempts to efficiently remove this pollutant have been relatively unsuccessful.

Mining Activities

Ground-water contamination associated with extensive mining operations is prevalent in the northeast, northwest, and, to some extent, in the southwest regions. Most mining operations encounter ground water, and disposal of the highly mineralized or acidic drainage water from mine working is the most prevalent cause of ground-water pollution. In Pennsylvania, for example, investigations have shown that coal mine drainage with high concentrations of iron and sulfate and an abnormally low pH has had a deleterious effect on both surface-water and ground-water quality over broad areas.

Other sources of ground-water contamination associated with mining activities include leachate from waste rock piles and leakage from tailing ponds. Uranium mine tailings in the Shirley basin of Wyoming are the cause of high concentrations of Ra_{226} in ground water. Metal sulfides contained in old mine tailings in the Coeur d'Alene basin of Idaho are the source of appreciable amounts of zinc in the local ground water.

A number of studies are being carried out in the various important mining States on the extent of water pollution from surface and underground mining. Closer control in the future will be given to the various potential sources of ground-water contamination associated with active mining operations, in order to protect ground-water quality. However, a major problem exists in how to deal with on-going cases of pollution from thousands of abandoned mines in all regions. In these instances public funds must be used, and the costs of the corrective measures typically are prohibitive. New Federal and State laws and regulations designed to minimize the impact on land use resulting from mining activities should be as concerned with aquifers as with the restoration of the visible environment and the protection of surface-water quality.

Salt-Water Intrusion

Intrusion of salty water into fresh-water aquifers in coastal areas is one form of ground-water contamination that has been widely recognized for many years in all four regions. Salt water occurs naturally in water table and artesian aquifers in coastal areas. Pumping from wells near salty ground-water bodies can induce the mineralized water to intrude into fresh-water zones.

The large number of individual and widely publicized cases of salt-water intrusion has led to the development of strict controls over diversion of ground water in the coastal plain States of the Northeast. These controls on pumpage, together with the general knowledge of well drilling contractors and ground-water users of where saline-water aquifers occur, has been most effective in eliminating salt-water intrusion as a critical problem in the region.

Contamination of wells with sea water does not appear to be a major problem in the Northwest. However, in the south central States, salt-water encroachment has affected a number of important and heavily pumped ground-water areas including Baton Rouge and Lake Charles in Louisiana and Houston, Galveston-Texas City, and Matagorda-Lavoca Bay in Texas.

In the Southwest, California has had serious problems of salt-water encroachment in many of its coastal basins. Various agencies in the State have established programs to reverse the movement of intruding saline water, the most well known of which involves the placement of a series of "barriers." The barriers, such as those in the Los Angeles area, are established by injecting non-saline water at a line of wells whose axis roughly parallels the ocean source. Some of these barriers have been successful in reversing the hydraulic gradient in the affected aquifer so that flow is toward the sea instead of toward fresh-water supply wells.

An even more critical problem in each of the four regions than salt-water intrusion in coastal areas, is that which can occur inland. Many inland fresh-water aquifers also are in direct contact with saline ground water. In most cases, the heavier mineralized water underlies the fresh water. Where wells are too deep or where excessive pumping modifies the hydraulic gradient, saline water may be drawn into zones formerly containing fresh water.

Unlike coastal intrusion, potential problems associated with inland saline ground-water bodies have not been studied in detail. Regulatory controls over diversion of ground water or well construction have not been developed to the degree that they have in coastal areas, and saline-water intrusion in inland regions will continue to be a significant problem.

Water Wells

Water wells under certain conditions can be sources of ground-water contamination. Typical examples are where a casing has been corroded or ruptured, where a well screen or an open bore hole interconnects two separate aquifers, where the surface casing has not been adequately sealed in soil or rock, or where an abandoned well is allowed to discharge salty water on to the land surface. Water wells can serve as a means for transmission of pollutants from one aquifer to another or from the land surface to an aquifer.

In some of the south central States, improperly constructed and abandoned water wells are considered by many public agency officials as the most significant cause of ground-water pollution. Contamination problems are especially prevalent in cavernous limestones, such as those in the Edwards plateaus of Texas and the Ozark plateaus of Arkansas. Unplugged wells tapping artesian brine aquifers have resulted in reported cases of contamination of shallow ground-water supplies in a number of counties in Texas.

In the Northeast, salt-water intrusion in coastal areas has been aggravated at numerous locations by the presence of corroded well casings, which allow salt water to enter fresh-water aquifers either from an underlying or an overlying saline-water aquifer or from an adjacent salty surface-water body. A classic example occurred in Baltimore, Maryland, where highly acidic industrial wastes in the water-table aquifer corroded the casings of more than 1,000 abandoned wells. Saline-water intrusion caused by pumping in the same shallow aquifer affected the deeper fresh-water artesian aquifer because the leaky, abandoned wells acted as conduits, allowing poor quality water to migrate into the deeper artesian aquifer.

A few of the States in the various regions have adopted regulations and codes governing well construction and the plugging of abandoned wells. However, it is difficult to enforce these regulations because records showing where operating water wells have been drilled over the past 50 years are incomplete. Better reporting of well data to public agencies is required. Licensing of well-drilling contractors in many States has been moderately effective in improving well construction practices. However, considerably more control is needed over the construction of domestic, industrial, and public supply wells and the fate of abandoned wells.

Agricultural Activities

A wide variety of agricultural activities, other than irrigation, have polluted ground water in all four study regions. Sources of contamination related to raising crops and livestock include: spreading of fertilizers, disposal of crop residues, man-caused changes in vegetation, storage of feedlot and barnyard wastes, mass burial of livestock, and application of herbicides and insecticides.

High nitrates are reported in ground water in many agricultural areas and fertilizers are certainly an important factor in the degradation of water quality. Animal waste from feedlots is a relatively new environmental problem because, until 10 or 15 years ago, most beef animals were raised on pasture land, where wastes were easily assimilated into the soil without significant surface- or ground-water contamination. However, with the increasing demand for more and better quality meat, concentrated feeding operations have been developed, and in Texas alone there were over two million beef cattle in feedlots during 1972. Most feedlots are capable of holding 1,000 to 50,000 head, and each animal produces about one-half ton of manure during its stay.

Nitrates in high concentrations have been found in soil profiles under a number of feedlots in both the south central and northwest regions. Few cases of ground-water contamination have been reported, but the potential of contamination from this source needs further study.

The most frequently mentioned cases of ground-water contamination from pesticides are those related to spills in the vicinity of a well or an irrigation canal that is infiltrating water to an aquifer. However, a few documented instances of contamination from the application of pesticides have been noted in the Northeast. For example, arsenate compounds used for insect control in the blueberry barrens of Maine have been found in shallow ground waters. In another case, water from a sand and gravel well in Massachusetts was contaminated by pesticides containing chlorinated hydrocarbons sprayed on cranberry bogs.

Pollution of ground water from agricultural activities is difficult to control. A high proportion of the problems are isolated in rural areas. Severe problems develop when former farm areas become urbanized, and ground-water use increases. Also, ground-water quality degradation can be aggravated by even heavier application of fertilizers and pesticides by individual home owners on relatively small lots.

Disposal Wells

Industrial waste, sewage effluent, spent cooling water, and storm water are discharged through wells into fresh- and saline-water aquifers in all four regions. The greatest attention in existing literature has been given to deep disposal of industrial wastes through wells drilled more than 1,000 feet into saline aquifers. Less than 300 such wells exist, and they represent a comparatively small potential problem when compared to the many thousands of shallow wells injecting pollutants into fresh-water aquifers.

For example only one or two deep disposal wells are operating in the northeast region and about 175 in the south central region. On the other hand, there are an estimated 5,000 "drain wells" in Idaho alone, that discharge domestic sewage effluent, excess irrigation water, street runoff, and even industrial wastes into the principal aquifer of the region. In Long Island, New York, approximately 1,000 "diffusion wells" inject about 80 million gallons per day of heated water from air conditioning or cooling systems into two of the principal aquifers tapped for public water supply. Thousands more, referred to as "sumps," are used for disposal of storm-water runoff. In Arizona, disposal of metal plating wastes into shallow wells by various electronic industries near Phoenix and Tucson was quite common at one time. All of these practices have led to ground-water quality degradation.

Few failures of wells used for deep disposal of industrial wastes in saline aquifers have been reported. This is probably due to the regulations and permit systems enforced by State agencies, mandating rigid testing and construction procedures. On the other hand, disposal of wastes to shallow wells has not been closely controlled. This has resulted in a large number of documented cases of severe ground-water contamination, frequently from the illegal use of shallow wells for the disposal of various types of hazardous waste.

Highway Deicing Salts

The use of large amounts of soluble salts for road maintenance during winter months has led to a significant number of cases of ground-water contamination in the Northeast. The problem is apparently not severe in the Northwest, and nonexistent in the other two regions.

There are two principal ways in which road salt can pollute ground water. Salt-laden runoff from roads can percolate into soils adjacent to highways and eventually reach the water table. The other source is related to storage of salt in piles at central distribution points. Rain falling on uncovered storage piles can dissolve the salt before infiltrating into shallow aquifers.

During the winter of 1965-66, the New York State Highway Department used 245,000 tons of sodium chloride. Massachusetts has applied more than 20 tons of salt per single-lane mile to its highways during a single winter season.

Because of the large amounts of salt spread and stored in the Northeast, water from many aquifers, especially sand and gravel deposits in the glaciated region, has shown a disturbing rise in chloride and sodium concentrations. In addition, complaints of salt contamination of water from individual wells is so common in New England that several States have established annual budgets to allow for replacement of affected wells.

There appears to be no adequate substitute for highway deicing salts. However, general recognition of the potential for polluting water supplies has resulted in many States in the Northeast embarking on programs to reduce the quantities of salt spread per winter storm. Equipment modification and driver education has been quite successful. In addition, although the practice is restricted by availability of funds, highway departments are enclosing many salt storage piles to protect them against contact with precipitation.

Miscellaneous Other Sources

Many other activities or sources of ground-water pollution have been encountered in the regional studies. For example, artificial recharge with treated municipal wastes and storm-water runoff can degrade ground-water quality.

A few significant cases of ground-water pollution have occurred in the Northeast and Northwest related to the infiltration of poor quality river water into aquifers tapped by public supply wells. In one instance in upper New York State, high counts of coliform bacteria suddenly showed up in water from a million-gallons-per-day municipal well after 19 years of trouble-free operation. The well is adjacent to the Susquehanna River, and excavation of fine material from the bed of the river, which is the principal source of recharge to the well, appears to be responsible for the problem. The bacteria-laden water traveled 180 feet through the sand and gravel aquifer tapped by the well.

The land treatment of municipal and industrial wastes by means of spray irrigation is a growing practice in all four regions. Only a few documented cases of ground-water contamination have been reported to date, but more monitoring and research are needed to determine the long-term impact on the resource.

Finally, land subsidence has been pinpointed as a source of ground-water contamination. High levels of arsenic in ground waters in a relatively small area west of Fresno, California, may be related to compression of clays. Arsenic, which has adhered to clay particles, goes into solution when the pressure is increased in the clay strata. The land subsidence process is the result of heavy ground-water withdrawals in the region.

RECOMMENDED PRIORITIES FOR GROUND-WATER QUALITY PROTECTION

There are two basic problems in dealing with ground-water contamination. The first is handling existing cases, and the second is preventing new occurrences. Each requires its own strategy.

A. Solving Existing Ground-Water Contamination Problems

1. Goals

- a. Protect the ground-water user.
- b. Prevent further degradation of water quality.

2. Control Measures

- a. Inventory sources of contamination.
- b. Define and monitor contaminated ground-water bodies that are considered hazardous.
- c. Control use of ground water already affected or threatened by contamination and provide alternate sources of water supplies where needed.
- d. Contain or clean up pollution where economically and technically feasible.

3. Research Needs

- a. New techniques for inventorying, monitoring, and defining instances of ground-water contamination.
- b. New techniques for effectively eliminating sources of pollution (i.e., modifications in septic tank design, methods for closing landfills, procedures and materials for lining waste lagoons).
- c. New techniques for removing pollutants from the ground (i.e., hydrocarbons, heavy metals) and methods for their disposal (i.e., landfill leachate, acid mine drainage).

B. Preventing Future Ground-Water Contamination Problems

1. Goal

- a. Protect ground-water resources.

2. Control Measures

- a. Prepare realistic guidelines and enforce regulations that are truly protective.
- b. Publicize new technology and how it is being utilized.

3. Research Needs

- a. Development of additional new procedures to minimize environmental effects of the various potential sources of contamination.
- b. More complete documentation of conditions at existing key sites of ground-water contamination as a guide to future research.

The most common approach toward existing problems is to attempt corrective action only after a specific incident of ground-water contamination has been discovered. This "brush-fire" approach is not suitable, taking into account the millions of ground-water sources presently in use and the potential threat to the health of individuals, in addition to possible adverse effects on industrial and agricultural activities. Locating and evaluating as many cases of ground-water contamination as possible should be a major concern to public agencies charged with the responsibility of protecting water quality. For example, for every landfill where pollutants have been discovered leaching into the underlying aquifer, there are hundreds more located in similar geologic settings and designed in the same manner, but for which no ground-water quality data are available. For every surface impoundment where it has been shown that pollutants are being added to the ground-water system, there are hundreds more being operated, unmonitored, under similar conditions.

A major effort should be directed, within the financial resources available to local, State and Federal agencies, toward defining the areal extent and severity of existing ground-water contamination problems. Such inventories can be used to warn against use of certain aquifers or portions of aquifers for specific purposes. Within the legal framework under which each State must operate, development or withdrawal of ground water could be limited in affected aquifer zones. It would be the task of the proper public agency to determine "critical zones" around each known significant case of ground-water contamination. In each "critical zone," ground-water diversion would be restricted from the standpoint of either the quantity that can be pumped or the purpose for which it can be used. Wells and other monitoring techniques would aid in determining when and how to modify the areal extent of a "critical zone" over a period of time.

Of course, a major benefit from an inventory of existing ground-water contamination sources would be an acceleration in the process of eliminating some of those activities that presently are introducing pollutants into the ground-water system on a continuous basis. Ground-water contamination in a number of categories can be controlled so that the problem does not increase in severity. These would include salt-water intrusion, which can be impeded by restrictions on pumping; leakage from surface impoundments, which can be halted by lining; and the spread of pollutants from a spill, which can be controlled in some cases by excavating the affected soil. Unfortunately, adequate measures and alternatives have not been developed for eliminating the source of contamination when dealing with such sources as extensive municipal landfills or use of highway deicing salts.

Equally as pressing as the need to develop methods and strategies for dealing with existing problems of ground-water contamination is the need to establish ways to prevent future problems. Almost every State in the four study regions has existing legislation which, although general in nature, would allow regulations and policies to be formulated and enforced for the prevention of ground-water quality degradation. Also, many codes in various States have been adopted to cover specific activities that can lead to ground-water contamination, such as those dealing with landfill siting, well construction, and sealing of surface impoundments.

Nevertheless, there has not been an over-all evaluation of the various options available to regulatory agencies for protecting ground-water quality. Such alternatives for control as the setting of ground-water standards, enforcement of land-use restrictions in critical areas, imposition of restraints on each individual type of activity that can lead to ground-water contamination, and regulation of patterns of ground-water use should be explored. Obviously, the choice of any control method must be influenced by geologic and hydrologic conditions in the area of interest and must take into consideration the type of activity involved.

One item that immediately becomes obvious from the various investigations is the need for more detailed analyses of water samples obtained from new and existing wells. Most analyses are presently run to measure non-toxic parameters. However, pollutants affecting ground-water quality are of such diverse nature and can originate from so many different sources that analyses should at least identify some of the more common pollutants that could be harmful to man. As more economic and reliable analytical techniques become available, routine analyses should be expanded to cover a wide variety of both inorganic and organic compounds.

The use and purpose of monitoring wells should be better understood. The general philosophy that monitoring wells are protective devices should be discouraged. Monitoring should be applied when there is a need to determine the status of ground-water quality at a particular location and to gain a perspective on long-term water quality at selected sites. At new sites, where a specific activity may lead to contamination of ground water, monitoring wells should be used only to determine whether procedures designed to protect ground-water quality have been successful. The monitoring wells themselves should not be considered as a method of preserving ground-water quality.

Unfortunately, the rate of new occurrences of ground-water contamination has not declined over the past decade in spite of increased efforts by local, State, and Federal agencies to protect ground-water resources from water-quality degradation. Even if new strategies are developed, implementation will not be possible with the present level of funding devoted to regulation and management of ground-water resources. Public agencies charged with the responsibility of protecting ground-water quality are presently understaffed, and authority appears to be splintered among too many organizations with diverse interests and capabilities. A basic need is a reevaluation of priorities governing budgetary allocations with a greater appreciation of the important role that ground water continues to play in meeting essential needs for high-quality water supplies.

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Rational Basis for Septic Tank System Design[a]

by Rein Laak, Kent A. Healy, and Dan M. Hardisty[b]

ABSTRACT

About 17 million families in the U.S.A. are served by septic tank and subsurface seepage systems. Rational design of these wastewater disposal systems includes three aspects. First the system must be hydraulically sound. This means that the flow regime and the storage and water carrying capacity of the receiving soil should be measured before design. A soil with a coefficient of permeability of less than 10^{-4} ft/min (5×10^{-5} cm/sec) suggests, for example, that the hydraulic capacity of the system governs the size of the subsurface leaching field. Seasonally high water tables or impervious strata may retard the flow and reduce the quantity of wastewater that can be carried away from the subsurface disposal area. In this case an elevated bed can be designed to increase the potential hydraulic gradient.

The second consideration concerns the biological mat in leaching fields. Leaching fields can be designed with higher loadings in soils having a greater coefficient of permeability than 10^{-4} ft/min (5×10^{-5} cm/sec) if increased pretreatment is used. A mathematical relationship was developed for reducing the size of leaching fields for effluents with a BOD_5 plus suspended solids less than 250 mg/l. Leaching fields were projected to operate indefinitely. Long-term loading rates for different soil permeabilities were plotted on a graph which can be used for sizing fields.

The third design consideration concerns preservation of the ground-water quality. The travel of phosphate and nitrogen has been studied by others and by the authors. Concrete sand and silt with an unsaturated thickness of 1.5 feet (38.1 cm) still removed after 2 years of operation 30% of septic tank effluent phosphate and nitrogen. The effluent from the test soils had a concentration of about 13 mg/l phosphate and 15 mg/l nitrogen mostly in the $NO_3^- - N$ form.

INTRODUCTION

It is reported that about 17 million families in the U.S.A. are served by soil seepage types of systems for the disposal of domestic wastewater.

Rational basis of designing soil seepage systems consists of three major considerations. First, the system must be hydraulically sound. This means that the flow regime including water use, wasteflow flux, treatment tank hydraulic properties, and the storage and water carrying capacity of the receiving soil should be measured or at least estimated before design drawings are prepared (Bradshaw, 1972; Johnston, 1971). The second major consideration concerns the biological clogging mat which is developed on the soil surface in the seepage field system (Winneberger *et al.*, 1960). The clogging mat under certain conditions could be the governing design factor in sizing the seepage field area. The third aspect of design deals with the preservation and protection of the ground- and surface-water quality.

HYDRAULIC CONSIDERATION

It is important that the water use for carrying of waste be carefully planned so that minimum wasteflow results. This can be achieved by providing "easy" repairs to leaky plumbing fixtures and by providing water saving devices such as spray faucets, waterless toilets or adjustable toilet flushes, no garbage grinders, etc.

The wastewater flow from households fluctuates. The total flow as well as the duration of peak flows become almost impossible to predict.

It has been customary to use mean maximum month flows for sizing the seepage beds which provide about 2 to 4 weeks storage between trench stones. The pipes from the house are supposedly sized using mean maximum hourly flows. Pipes past the treatment tank, septic tank, could be small because peak flows have now been reduced by the tank's surface area.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

[b] Associate Professor, Associate Professor, and Graduate Student, respectively, Department of Civil Engineering, University of Connecticut, Storrs, Connecticut 06268.

The hydraulic conductivity of a seepage field is defined as the number of gallons of clear water per day that can be absorbed by the field. The conductivity of a field is dependent on the permeability of the soil, the geometry, the position of any impermeable boundaries, the position of the water table, and evapotranspiration. Seepage fields in temperate zones should be designed to function under gravity flow potential only, if they are to perform satisfactorily year round.

Knowing the boundary conditions and the permeability of the soil, and assuming no evaporation and steady state flow due to gravity potential, it is possible to calculate the hydraulic conductivity of a seepage field that can be used for design. The thin zone of reduced permeability at the soil interface can be ignored if it is assumed that a head of one foot (30 cm) due to flooding in the trench will be available to push the liquid through this zone. If the soil surrounding the field can carry the liquid away faster than one foot (30 cm) of head supplies it, there will be, in addition, capillary head available to pull the liquid through this thin zone. With this capillary head, one foot (30 cm) of flooding will not occur.

Flow nets for a variety of positions of the ground-water table and bedrock were drawn, using an electrical analog, showing the pattern and amount of ground-water flow from a 3-trench seepage field. These flow nets are 2-dimensional and represent a cross-sectional flow pattern. The flow per running foot of field can be calculated using Darcy's Law.

In order to simplify the design procedures, a seepage field consisting of 3 parallel trenches, 2 feet (0.6 m) wide, 2½ feet (0.75 m) deep, and 8 feet (2.4 m) on centers was chosen as a reasonable and efficient system. Variation in capacity is obtained by varying the length of the field. This system is a total of 18 feet (5.4 m) wide and, if the effluent is assumed to flood the trench to a depth of 12 inches (30 cm), has a soil interface area of 12 square feet per running foot (3.64 m^2/m) of field. It was found that if the relative hydraulic conductivity Q/K per foot of field was plotted versus the distance from the bottom of the trench to an impermeable strata (H_I) plus 5 times the distance from the bottom of the trench to the original external water table (H_W), a fairly continuous curve resulted as is shown in Figure 1 (Healey and Laak, 1973). This curve allows the effect of an impermeable strata and the effect of the water table to be considered together.

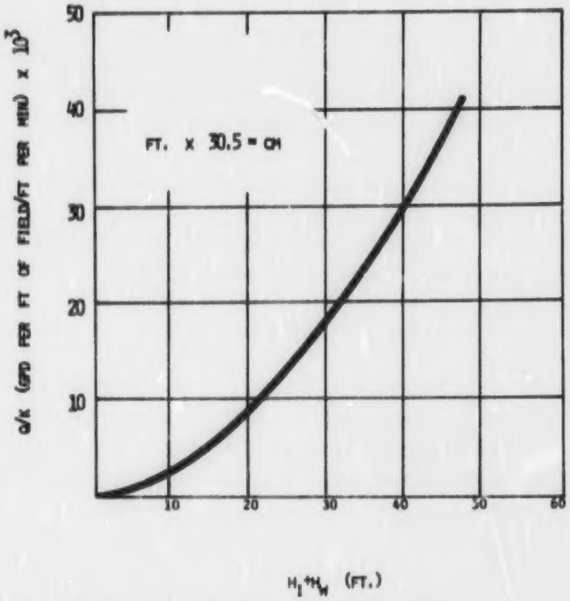

Fig. 1. Hydraulic conductivity of 3-trench field.

CLOGGING MAT CONSIDERATIONS

Many engineers and health officers feel that all seepage fields have a finite life. The authors theorized, however, that at some loading rates, decomposition would match accumulation and growth, and absorption could continue indefinitely under this long-term loading rate.

Work done by investigators (Thomas *et al.*, 1966; Laak, 1970; Jones and Taylor, 1965; Winneberger *et al.*, 1960; Coulter *et al.*, 1960; Orlob and Butler, 1955; Bouwer, *et al.*, 1972; Kropf, 1972; and Kropf *et al.*, 1974) was reviewed to determine their findings. In all the investigations, it was observed that the reduction in permeability of the soils due to biological growth and clogging occurred in the top 2 inches (5 cm) of the soil sample. The results of these previous investigations observed that 100 to 200 days after loading began, a low but relatively constant rate of acceptance occurred.

Different hydraulic heads had been used in the cases reviewed and the results of tests by Healy and Laak (1973) and Jones and Taylor (1965) had shown that the long-term acceptance rate was dependent on the hydraulic head. These tests indicated that going from a hydraulic head of a few inches to several feet could double the long-term acceptance rate. The rates measured by other investigators were therefore adjusted to approximate the rate that would have occurred if the head had been one foot (30 cm). A plot of adjusted long-term acceptance rate versus soil permeability is given in Figure 2.

These conclusions are substantiated by the results of the study done for the FHA by the Robert Taft Sanitary Engineering Center (Coulter *et al.*, 1960). An approximation of the permeabilities of soils encountered in the FHA study was made and these data are shown as solid dots in Figure 2.

All of the data surveyed indicated that there is a long-term acceptance rate at which a seepage field will operate almost indefinitely if a sufficient hydraulic head (one foot or 30 cm a minimum) is available to push the liquid through the zone of reduced permeability at the soil interface (Figure 2) solid line. This curve applies to a domestic septic tank effluent. If the domestic sewage is treated to a greater degree, higher loadings are possible. A study by Laak (1970) shows that the seepage area can be adjusted as follows:

$$\text{Adjusted Area} = \begin{array}{c}\text{Septic Tank}\\ \text{Effluent Area}\end{array} \sqrt[3]{\frac{BOD_5 + TSS}{250}}$$

where BOD_5 and total suspended solids (TSS) are expressed in mg/l as per treatment unit effluent.

PRESERVATION OF WATER QUALITY

The reactions that nitrogen may undergo while passing through soil include (1) mineralization—breakdown of organic nitrogen to ammonium; (2) nitrification—biological oxidation of ammonium to nitrate; (3) adsorption – attachment to soil particle surfaces; (4) ion exchange—ions in the percolating water replace ions attached to soil particles; (5) fixation—permanent immobilization of the molecules by entrapment between clay layers or formation of stable complexes with the organic fraction; (6) volatilization—vaporization of ammonia at high pH; (7) biological uptake—incorporation of nitrogen into plants or microorganisms; and (8) denitrification—biological conversion of nitrate to nitrogen gas.

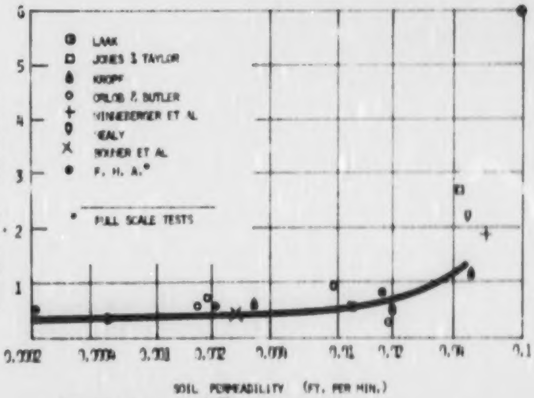

Fig. 2. Long-term acceptance rate of effluent by soil.

In a leaching field, wastewater percolates through several feet of unsaturated flow in the zone of aeration. In this situation the predominant reaction expected is nitrification. Unfortunately, the nitrate ion flows with soil water and may pollute potable well water supplies.

In leaching field systems located in or near to the ground-water table, anaerobic conditions often prevail. In this case the nitrogen remains in the NH_4^+ form and can be adsorbed. Adsorbed ammonium, however, is subject to plant uptake if in the root zone, and to nitrification if the soil becomes aerobic once again.

Phosphate fixation by soils primarily depends upon the pH of the soil and the presence of aluminum, iron, calcium, and organic colloids. Fixation is maximum at the extremes of pH and minimum at pH = 6-7. It is reported that most soils have high long-term fixation capacities, but numerical values too often are missing.

At pH less than about 5, simple precipitation of $M\,(OH)_2\,H_2PO_4$ (M can be Al^{+++} or Fe^{+++}) is favored. If soil pH is more mildly acid (pH about [illegible] phosphate is adsorbed onto weakly acidic hydroxy polymers forming $M\,(H_2O) \times (OH)\,y\,H_2PO_4$. Both the above reactions occur in two steps; the first is the rapid (reaction time less than a day) precipitation or adsorption of phosphate as described above. The second is caused by slow breakdown of clay structure in the presence of phosphate releasing additional aluminum or iron. The phosphate is then fixed by the released metal. The clay decomposition is caused by the upset of the aluminum-silical equilibrium in solution. That is as the metal precipitates with the phosphate.

In calcareous or alkaline soils, fixation is caused by the formation of an entire series of insoluble calcium phosphates in a very heterogeneous form. There is evidence that Al^{+++} or $Al\,(OH)_3$ can fix phosphate even in alkaline soils. This is partially a function of other ions.

To investigate the ability of soils to remove nitrogen and phosphorus, septic tank and oxidation pond effluents were passed through 18 inches of aerobic unsaturated soil in experimental soil boxes constructed to simulate leaching trenches. Two soils, concrete sand and silt were used.

It was concluded that 18 inches of soil can remove roughly 30% of the phosphate on the average. Total nitrogen removals were erratic varying from release of nitrogen to an average of 30% removal. Higher removals were expected but it was reasoned that 18 inches of soil was insufficient for complete removal. The lagoon-soil total system and septic tank soil total system were able to remove 60-80% of the phosphorus.

The soil box effluents were usually 80-90% nitrified, producing effluents with roughly 15 ppm NO_3-N. This represented a 50% removal of nitrogen by the lagoon-soil total systems and septic tank-soil total system.

The removal of nitrogen and phosphorus with pretreatment and 18 inches of soil was considered excellent since in actual field conditions wastewater effluent usually must pass through a much greater distance in the soil.

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DISCUSSION

The following questions were answered by Rein Laak after delivering his talk entitled "Rational Basis for Septic Tank System Design."

Q. by Fred C. Saxon. *What effect does your design have on the bacteriological quality of the water leaving the field?*

A. Our design is not a design but rather a method of sizing fields by following a procedure. Our method or criteria does not prevent anyone from providing maximum preventive measures by requiring long distances to wells, etc. The bacteriological quality of the water leaving the field is the same for a given soil of unit thickness with same boundaries and loading patterns. We stress that the clogging mat should be left intact (i.e. no resting) to provide maximum treatment through it.

C. by Philip Wagner. *In your abstract you mention storage. What is your rational basis for storage evaluation of leach fields? Regulatory standards for "separation distances" appear to be arbitrary, but have you calculated storage coefficients needed?*

A. Storage in leach fields equals the yield or approximately the volume of spaces between stones. This storage volume available can store peak flows or overloads when they occur. The acceptance rates into soil are variable due to clogging mat permeability flux and sometimes the position of the ground-water table. The exact storage required cannot be calculated because we have no exact data on flow flux v.s. acceptance rate flux. The distance between trenches has nothing to do with storage in the stones, but may have to do with the mounding of ground-water table and storage in soil itself during nongrowing season.

Q. by G. Morgan Powell. *Why did you assume saturated flow below the drain line for equation calculation? Is this in reality saturated? If so, why do you state unsaturated flow 18 inches below the lines for N and P data?*
A. Saturated flow was assumed to represent the worst condition, i.e. near failure. In reality, it probably, most of the time, is not saturated. For design it is customary to find the worst case or the maximum it can take—for sizing.

Q. by John L. Wilson. *What are the mechanisms work to remove N and P in the unsaturated zone existing in sand which you investigated? Was N removed by denitrification, or by plants growing at the leaching field site?*
A. The possible mechanisms of removals are listed in the paper. Nitrogen was possibly removed by denitrification after it was nitrified in soil, and also by adsorption of ammonia in anaerobic regions and possibly by grass roots. We did not study the mechanisms but measured the removal quantity.

Q. by Lyle V. A. Sendlein. *How did you determine K in the laboratory and how reliable do you think it is?*
A. We did not determine K in laboratory. K values were determined in field using falling head permeameter and "undisturbed" samples. K values determined were within a magnitude of two to five fold which is ample accuracy to size leaching fields.

Q. by Ken Webb. *By what mechanism is the nitrogen removed through the 18 inches of sand filtration?*
A. Nitrogen removal mechanisms were not studied but rather the quantity removed was measured. The nitrogen could have been removed (a) in anaerobic zone by adsorption of ammonia; (b) by biological uptake by grass roots and microorganisms; (c) denitrification—some nitrogen could have been denitrified after having been nitrified; and (d) possibly by other mechanisms such as volitilization and fixation.

Effects of Septic Tank Effluent on Ground-Water Quality, Dade County, Florida: An Interim Report[a]

by William A. J. Pitt, Jr.[b]

ABSTRACT

At each of 5 sites in Dade County, where individual (residence) septic tanks have been in operation for at least 15 years and where septic tank concentration is less than 5 per acre, a drainfield site was selected for investigation to determine the effects of septic tank effluent on the quality of the water in the Biscayne Aquifer.

At each site 2 sets of multiple depth wells were drilled. The upgradient wells adjacent to the drainfields in most places, were constructed in such a way that the aquifer could be sampled at 10, 20, 30, 40, and 60 feet below land surface. The downgradient wells at each site are 35 feet or more from the upgradient wells in the direction of ground-water flow, and allow the aquifer to be sampled at various depths.

Except at one site, no fecal coliforms were found below the 10-foot depth. Total coliforms exceeded a count of one colony per ml at the 60-foot depth at 2 sites. At one site a fecal streptococci count of 53 colonies per ml was found at the 60-foot depth and at another a count of 7 colonies was found at the 40-foot depth. The 3 types of bacteria occur in higher concentration in the northern areas of the county than in the south. Bacteria concentrations were also higher where the septic tanks were more concentrated.

INTRODUCTION

The U.S. Geological Survey has completed an interim report of the first year of a 3-year investigation to determine the effects of septic tank effluent on ground-water quality of the Biscayne aquifer of Dade County, Florida. The investigation is in cooperation with the Dade County Manager's office, the Dade County Pollution Control Department, and the U.S. Environmental Protection Agency. The University of Miami, under a separate contract with the county, is also involved with the investigation in an effort to determine the effects of viruses in septic tank effluent on the ground-water quality.

SCOPE

The investigation studied only possible contamination from septic tanks in areas where individual sewage disposal units (septic tanks) have been in use for more than 15 years and where the septic tank concentration is 4 or less per acre. All the areas investigated are west of the salt front.

This report has been prepared to fulfill the requests of many for an interim report on the investigation. It is not intended as a final report, and the data and statements contained therein are subject to change after all the data are available. This report contains all the water quality data collected at the areas selected for investigation in Dade County. The data include physical, biological, and chemical parameters.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974. Prepared as Open File Report 74010 by the U.S. Geological Survey in cooperation with Dade County, Florida.

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Table 11. Homestead (high density)–Bacteria colonies per 100 ml.

(A complete copy of this report–Open File Report 74010–is available from the U.S. Geological Survey, 325 John Knox Road, Suite F240, Tallahassee, Florida 32303.)

DISCUSSION

The following questions were answered by William A. J. Pitt, Jr., after delivering his talk entitled "Effects of Septic Tank Effluent on Ground-Water Quality, Dade County, Florida: An Interim Report."

Q. by Lynn W. Gelhar. *What is the rate of natural recharge in the study area?*

A. F. W. Meyer in his U.S.G.S. open-file report 71003 indicates that of the average annual rainfall of 60 inches, the average annual water loss was 4.4 inches, and the average annual runoff was 16 inches. He calculated the natural evapotranspiration as 40 inches per year, and the consumptive use to be 2 inches per year.

Q. by Lynn W. Gelhar. *What were the nitrate levels in the shallow ground water?*

A. The sandy sites had nitrate levels very close to 0. The highest value recorded there was 0.07 mg/l as NO_3. In the southern sites (the limestone areas), nitrates ranged from 0.01 mg/l to 2.10 mg/l with the average somewhere around 1.5 mg/l.

Q. by Edwin A. Ritchie. *What were the horizontal distances that the bacteria moved from the various sites?*

A. In North Dade, one of the sandy sites, the bacteria traveled 50 feet to the downgradient wells.

In Hialeah, another sandy site, no bacteria were found 95 feet downgradient. In Bird Road-Galloway and the two Homestead sites, the bacteria traveled 35, 90, and 50 feet respectively. All of these three sites are in the highly permeable limestone areas. The above values hold true for both total coliform and fecal strep., but fecal coliform were not detected at the downgradient wells in the sandy areas.

Q. by G. F. Hendricks. *How long were the 5 septic tank study sites operated prior to study?*
A. The minimum age was 15 years (the Hialeah site). The oldest operating tank was in the low density Homestead area which has been operating over 30 years. The other sites have been in use for over 20 years.

Q. by Robert C. Minning. *What detection method did you use for the Rhodamine WT velocity study?*
A. A fluorometer was used. Even though most of the samples could be identified with the naked eye, we used a fluorometer so that we could determine the peak of the concentration plume.

Q. by Dennis E. Gray. *What is the mean vertical distance separating the bottom of the study drainfields and the water table?*
A. All the sites studied have been in operation for more than 15 years so that the owners do not know or do not remember how deep the drainfields are. However, if we assume them to be at least 2 feet below land surface, which is the present requirement, then the distance to the water table is 2 to 5 feet below the bottom of the drainfield.

Subsurface Sewage Disposal and Contamination of Ground Water in East Portland, Oregon[a]

by E. L. Quan[b], H. R. Sweet[c], and Joseph R. Illian[d]

ABSTRACT

Over the past 30 years East Portland and central Multnomah County have metamorphosed from a rural-suburban to a locally urban community. Services, including community water and sewer have been extended to most of the area. However, a 30-square-mile (80 km^2) area within central Multnomah County remains unsewered today. This area reportedly disposes of 8 to 10 mgd (34,400 m^3/day to 38,000 m^3/day) sewage via subsurface systems, i.e. cesspools, seepage beds, and drainfields. These methods of waste disposal have resulted in the degradation of the ground-water resource within the study area.

Most of the developed area is located on a relatively level terrace made up of Pleistocene fluviolacustrine sediments. Partially cemented gravels of the Pliocene Troutdale Formation underlie the terrace deposits. Both of these units are generally excellent aquifers where saturated. The depth to water in the unsewered area ranges from about 100-200 feet (30 to 60 m) in the southern terraced area to less than 10 feet (3 m) in much of the northern area underlain by younger, floodplain, terraces adjacent to the Columbia River.

Central Multnomah County is situated within a regional ground-water discharge zone. It receives ground-water recharge from the Cascade Mountains to the east and intermediate recharge from the Cascade foothills and other isolated hills bordering and within the study area. The major surface drains receiving ground water from the regional and intermediate flow systems are the Willamette, Clackamas, and Columbia Rivers.

The fluviolacustrine terraces constitute a local recharge zone. The primary ground-water recharge source is infiltrating precipitation as evidenced by the paucity of natural surface drainage, although the area receives in excess of 40 inches (100 cm) of precipitation per year. However, due to development and its attendant reduction in area for infiltration, e.g. paving and building, there has been a decrease in natural recharge. The estimated 8 to 10 mgd (34,400 m^3/day to 38,000 m^3/day) of domestic waste which is disposed of via the subsurface is thus introduced as supplemental local recharge.

Infiltrating precipitation and sewage effluent migrates downwards through the water table. The depth to which the local recharge can penetrate the water table is limited by its hydraulic potential and the vertical hydraulic conductivity of the substrata. Therefore, the NO_3-N contaminated recharge is effectively buoyed up and migrates laterally along the upper portion of the water table to its eventual surface drain, Columbia Slough South Arm.

Water samples from wells developing water in adjacent or upgradient sewered areas and/or from deeper aquifers within the unsewered area generally have NO_3-N concentrations of less than 1 mg/l. Shallower wells and springs within the unsewered area and South Arm Slough, downgradient grom the unsewered area, had NO_3-N concentrations ranging from 4.7 to 11.86 mg/l, with a mean value of 7.74 mg/l in July 1974.

INTRODUCTION

The Columbia Slough is a small dead-ended waterway located in North Portland and North Multnomah County, Oregon. The entire length of the slough lies in a flat valley that is bordered by minor agricultural areas, industries, swampy lands, and the northern sector of the Portland Metropolitan area. It is fed by large spring flows, area surface water and subsurface drainage. The slough has a flat gradient which causes it to flow slowly, and its lower section is substantially influenced by responses in the Willamette and Columbia Rivers to tidal changes in the Pacific Ocean.

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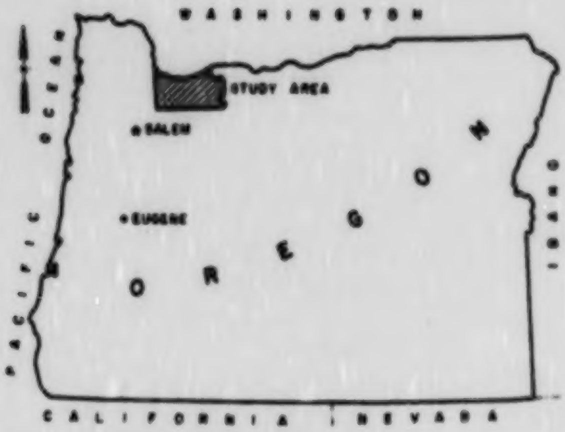

Fig. 1. Location of East Portland study area.

The study area (see Figure 1) in East Portland of Multnomah County, Oregon, has received wide attention from governmental agencies and citizen groups for many years. During 1972, the City of Portland, Multnomah County, Port of Portland, Corps of Engineers, and the Department of Environmental Quality formed the Columbia Slough Environmental Improvement Task Force for the purpose of bringing together the land-use plans proposed for the Columbia Slough area. Numerous meetings were held with members of the public and organized citizen groups. The major topics considered by the Task Force and the public involved flood control, land-use patterns, fish and wildlife, recreation, and water quality improvement for the development of the Columbia Slough area.

Water quality studies in the Columbia Slough were started in 1971 and completed in 1973 by the Department of Environmental Quality. Most of the data were collected during the dry weather period. The chemical data indicated that the spring sources forming the headwaters of the South Arm Slough were unusually high in nitrate-nitrogen (NO_3-N) and sulphate ion concentrations. It was suspected that the area lying directly south of the South Arm Slough was contributing much of the NO_3-N via subsurface disposal of domestic waste. The State Engineer's Office was requested to assist in the interpretation of the data.

The area lying directly south of the Columbia Slough drainage system changed from an agricultural to suburban-urban area over the past 30 years. Household waste disposal is primarily by means of cesspools (see Figure 2), and septic tanks and seepage beds. The area estimated to be served by subsurface waste disposal in central Multnomah County covers about 20 square miles (50 km^2) (Moffatt and Taylor, 1965). In addition, about 7 square miles (18 km^2) along the eastern border of Portland are currently served by cesspools and septic tanks (see Figure 3). Several square miles along the west boundary of Gresham are also served by subsurface disposal systems. The population within this area served by subsurface systems was estimated to be 102,000 persons in 1972, discharging an estimated 10 million gallons per day (mgd) (38,000 m^3/day).

The purpose of this paper is to describe the study area geology, hydrology, hydrogeology, and to compare the water quality in wells within the unsewered area to those in the sewered area of east Multnomah County, Oregon. The study is also concerned with developing general recommendations for alleviation of the contamination problem.

GEOLOGY

The geology of the East Portland area has been described by Treasher (1942), Trimble (1957, 1963) and more recently by Hogenson and Foxworthy (1965) (see Figure 4). Underlying the area are older volcanic and sedimentary rocks ranging from Eocene to early Miocene in age. Only one well in the East Portland area has penetrated these older rocks. This well derived little water from the older rocks.

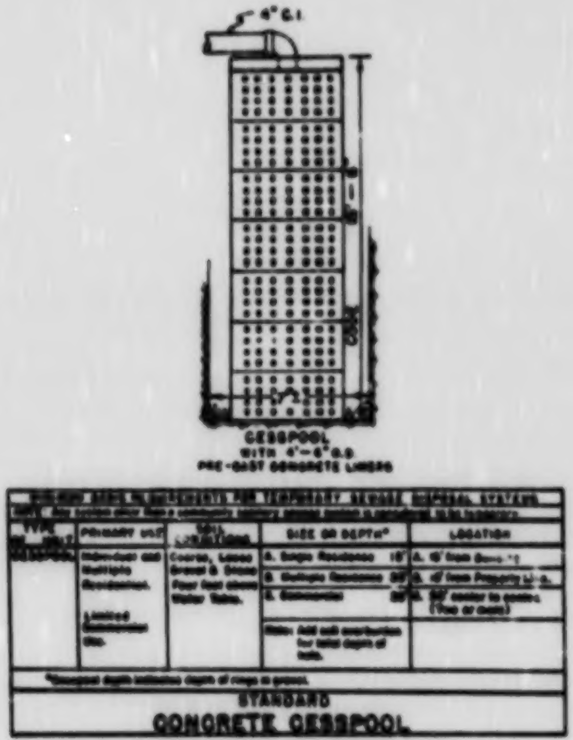

Fig. 2. Typical cesspool design for East Portland.

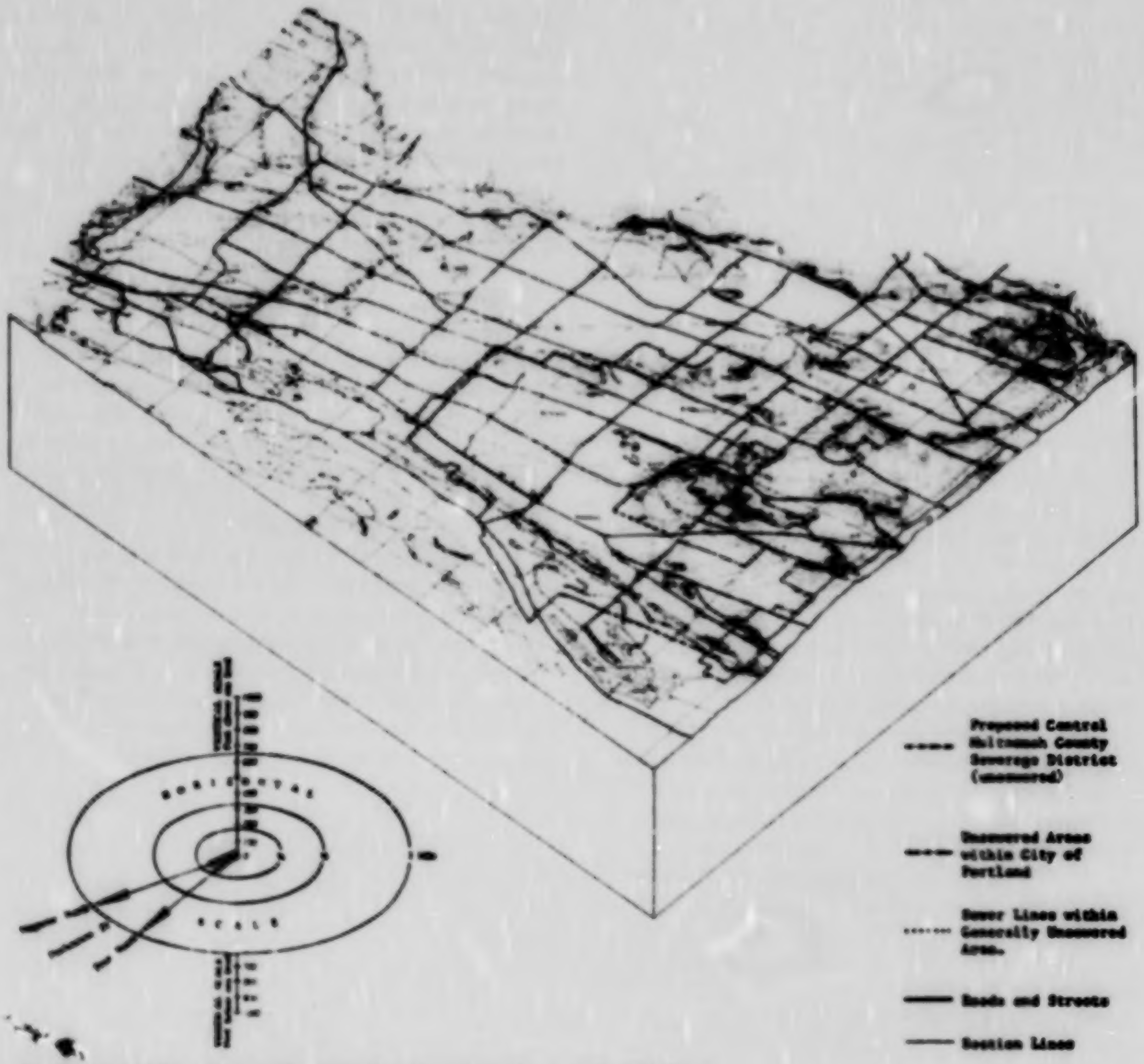
Proposed Central Multnomah County Sewerage District (unsewered)
Unsewered Areas within City of Portland
Sewer Lines within Generally Unsewered Area.
Roads and Streets
Section Lines
HORIZONTAL
SCALE

Fig. 3. Topography, major roads, sewered, and unsewered area in East Portland.

Unconformably overlying the older rocks are a sequence of accordantly layered basaltic lava flows of the Columbia River Group of early Miocene age. Individual flows in this unit range in thickness from about 10 to 150 feet (3 to 45 m) and can be traced laterally for distances ranging from less than one to as much as three miles (8 km). The thickness of the Columbia River Basalt in the study area ranges from about 120 feet (37 m) in the Fairview area to perhaps several hundred feet (90 m) in the west portion of the study area. Columnar, cubic or "brickbat," and platy jointing are present in the various flows. These together with the scoriaceous and fractured materials in the interflow zones are the major avenues for water movement. Water wells penetrating these interflow zones yield moderate to large quantities of water.

The Columbia River Basalt is unconformably overlain by the Sandy River Mudstone of early (?) Pliocene age. This unit is primarily made up of indurated clay and silt, probably of lacustrine origin. It also includes minor amounts of sand and fine gravel, especially near the base of the unit. The maximum known thickness of the unit in the study area is about 900 feet (270 m). Though most of the unit is saturated with ground water, it does not readily yield water to water wells, because of its relatively low hydraulic conductivity.

Unconformably overlying the Sandy River Mudstone is the Troutdale Formation of early Pliocene age. This unit consists mostly of well-indurated sandy conglomerate with local layers of stratified claystone and siltstone. The thickness of the Troutdale Formation in the study area ranges from about 150 feet (46 m) near Sandy to about 360 feet (110 m) at Fairview. Bedding in the Troutdale Formation dips slightly towards the west as a result of initial deposition by westward-flowing streams and subsequent tilting during the deformation that formed in Portland structural basin. This unit is the major aquifer in the study area.

Overlying and in places intruding the Troutdale Formation are basaltic lava, tuff, and volcanic cinders of the late Pliocene to late (?) Pleistocene Boring Lava. This unit crops out at Kelly Butte, Rocky Butte, and Mount Tabor in the study area (see Figure 4). The Boring Lava was deposited on an undulating erosional surface developed on top of the Troutdale Formation. The Boring Lava is primarily unsaturated.

A unit mostly made up of clay, silt, sand, gravel, and mudflow deposits underlies much of the area to the southeast of the study area. Hogenson and Foxworthy (1965) refer to this unit as "piedmont deposits." The thickness of these deposits is commonly less than 100 feet (30 m) but at places nearly 200 feet (60 m). The materials in this unit generally have a low hydraulic conductivity and do not readily yield water to wells.

Poorly consolidated and unconsolidated gravel, sandy silt, and clay, deposited by the ancestral Columbia River and its tributaries on the eroded surface of the Troutdale Formation during the late Pleistocene make up the Portland terraces. The materials were deposited during a time when the surface drainage system was at a level several hundred feet above its present channels. These fluviolacustrine deposits are relatively coarse-grained and include boulders in the northeastern part of the study area. They grade into predominantly finer-grained materials to the west. Throughout the area the gravels are poorly sorted and commonly include a fine-grained matrix. These terrace materials feather-out in places but are as thick as 250 feet (76 m) in much of the area. They are not generally saturated but are moderately permeable and yield small to large quantities of water to wells where they extend below the water table.

The broad plain along the Columbia River is underlain by Recent alluvial materials. The depth of this Recent fill is as great as 175 feet (54 m) in the study area. The upper portion of this unit is composed mainly of sand, silt, and clay, while deeper parts include some gravelly layers. Shallow wells, tapping the finer-grained materials yield only small to moderate amounts of water. Deeper wells which tap the gravelly layers yield larger quantities.

HYDROLOGY

Major surface-water drains in the East Portland area include the Columbia River to the north; Johnson Creek, a tributary of the Willamette River, to the south; and the Sandy River and its tributary, Beaver Creek, to the east (see Figures 3 and 5). Although the Portland area receives over 40 inches (100 cm) per year of precipitation, there is a noticeable paucity of surface drainage systems on the terrace area. This is due to the high hydraulic conductivity of the terrace materials and was the case even before extensive development of the area took place.

Fairview Creek flows from Grant Butte to Fairview Lake. The out-flow from Fairview Lake forms the upper Columbia Slough and the main drainage canal of Columbia Slough which flows west, subparallel to the Columbia River. South Arm Slough begins as spring flow about 2½ miles west of Fairview Lake. South Arm Slough flows parallel to and is located immediately south of the main drainage canal of Columbia Slough (see Figure 3). South Arm Slough is connected to Columbia Slough by a small channel located nearly 2 miles below its headwaters. Its main confluence with the slough is southwest of Portland International Airport. Perennial flow in upper South Arm Slough is through the small channel. During the dryer summer months, flow from lower South Arm is also through the smaller channel into Columbia Slough. On the other hand, during wet, winter-weather periods, the flow is generally through South Arm to its main confluence with Columbia Slough. In addition to natural surface runoff, 12 storm sewers ranging from 12 to 60 inches (30 to 150 cm) in diameter discharge to Fairview Lake, South Arm, and Columbia Slough in the study area. The study area does not have extensive storm drain development. Most of the drains are associated with the primary roads in the area. Spring discharge, base flow, and bank storage are the major sources of water during the summer months when this system is made up of gaining streams. Flow measurements in Columbia Slough range from about 70 to 176 cubic feet per second (cfs) (2 to 5 m^3/sec) and it has been estimated that the upper 1¾ miles (3 km) of South Arm Slough (primarily

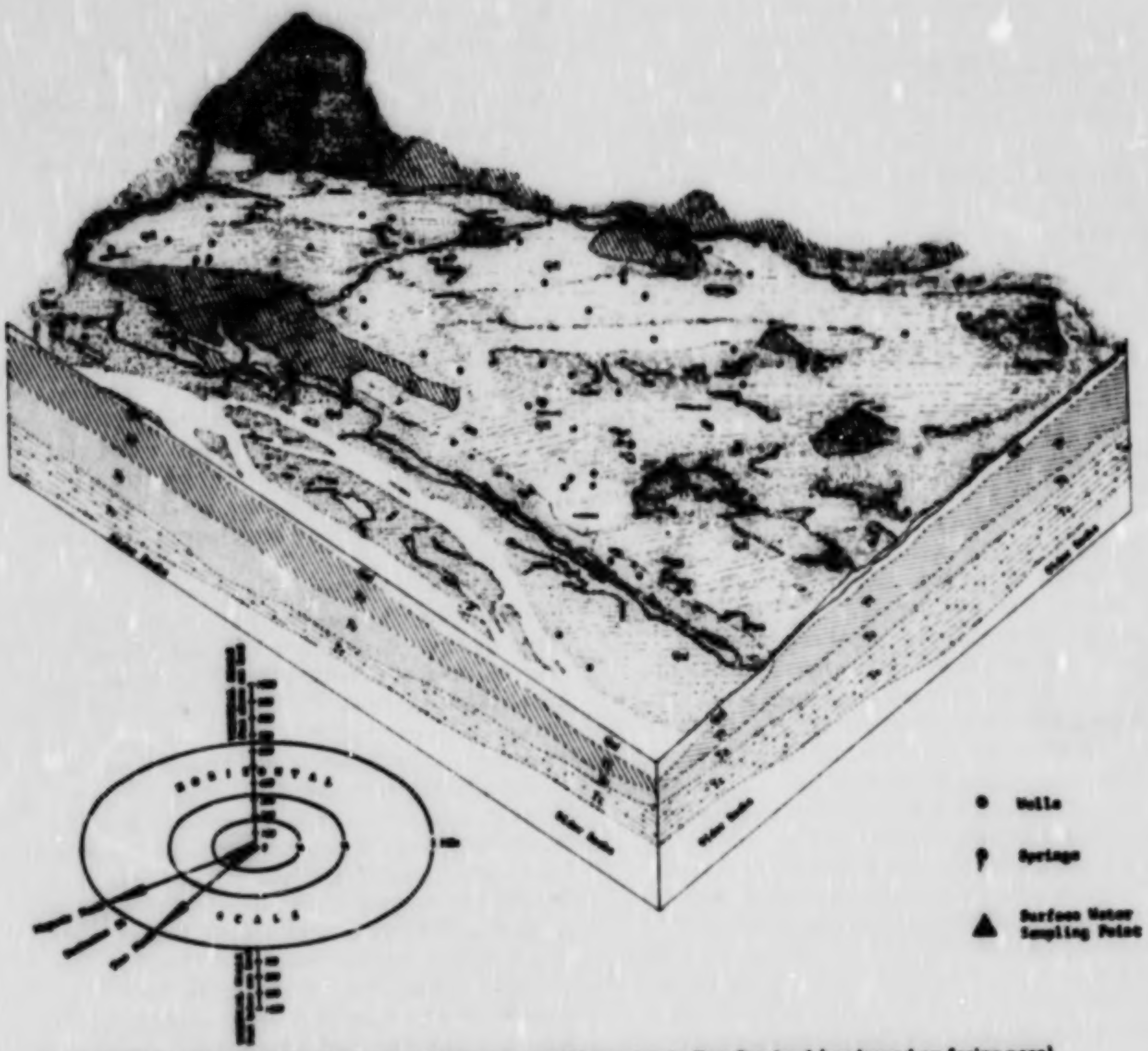

Fig. 4. Geology, selected water wells, and surface-water sampling points in East Portland (see legend on facing page).

spring discharge) contributes about 26 percent of the total flow in upper Columbia Slough during dry weather.

HYDROGEOLOGY

Stratigraphic relationships and aquifer characteristics in the study area are outlined in the earlier text with the geology and summarized in the legend on Figure 4. The major aquifers in the study area include the fluviolacustrine deposits where saturated and the more transmissive portions of the Troutdale Formation. Because of its general low hydraulic conductivity, the Sandy River Mudstone does not readily provide water to wells. Some wells in the Portland area develop water from interflow zones in the Columbia River Basalt. However, its great depth in the study area and the availability of water in the shallower Troutdale Formation has resulted in little development of this deeper aquifer.

The Columbia River and its floodplain, including the Columbia Slough system is situated in a ground-water discharge area. The Cascade Mountains to the east are the major source of recharge to the regional flow system. Most of the water movement in this regional system probably takes place in the deeper substrata, i.e. the older rocks and perhaps the Columbia River Basalt. Although potential gradients may be great, actual movement of the water in the regional system is probably extremely slow, primarily because of the low hydraulic con-

Qal

YOUNGER ALLUVIUM

Gravel, sand, silt, and clay; slightly stratified. Mostly well sorted beneath flood plains of larger rivers; less sorted near smaller streams. Thickness generally a few feet near small streams, about 20 or 30 feet along Sandy and Clackamas Rivers, 75 to 100 feet along Willamette River, and as much as 200 feet along Columbia River. Layers of well-sorted gravel and sand yield large amounts of water to wells; less sorted and finer grained materials yield smaller amounts.

Qfl

FLUVIOLACUSTRINE DEPOSITS

Unconsolidated gravel, sand, silt, and clay; slightly stratified. Generally bouldery and coarser grained to the east and progressively finer grained to the west side of the area but contains some gravel layers throughout most of the area. Thickness generally less than 100 feet; locally, it may be as great as 150 feet. Gravel and sand beds are permeable but are mostly above regional water table and are unsaturated or yield only small amounts to wells from perched water. Where permeable beds extend below the regional water table, they yield moderate to large quantities to wells.

Qp

PIEDMONT DEPOSITS

Mostly silt and clay, but includes some sand gravel, and mudflow deposits. Underlies the Kelso slope and sic upland valleys to depths generally less than 100 feet. Generally nonwater bearing or yields only small quantities to wells and springs from perched water.

Qtv

BORING LAVA

Mostly gray massive basaltic lava; contains lesser amounts of tuff and volcanic cinders. The lava occurs mostly as flow layers but includes sills and feeder dikes. Total thickness ranges from 5 to about 800 feet. Generally is above regional water table and yields only small to moderate amounts to wells and springs from perched water.

Tt

TROUTDALE FORMATION

Unconsolidated and partly consolidated gravel, sand, silt, and clay, commonly in the form of well-indurated sandy conglomerate. Thickness generally more than 100 and locally more than 800 feet. Layers of permeable gravel and sand below regional water table yield moderate to large amounts of water to wells and springs; similar beds above regional water table yield smaller less dependable supplies from perched ground water.

Ts

SANDY RIVER MUDSTONE

Principally mudstone, claystone, and partly consolidated silt and clay but includes minor beds of sand and gravel. Total thickness is at least 900 and probably more than 1,000 feet. Generally impermeable and non-water bearing, but a few wells obtain small amounts of water from local layers of sand and gravel.

Tc

COLUMBIA RIVER BASALT

Dark basalt in accordantly layered flows that range from about 10 to 150 feet in thickness; total thickness 800 feet or more. Permeable zones at contacts between some flows yield moderate to large amounts of water to wells that penetrate the basalt below the regional water table and yield lesser amounts to springs and wells from perched ground water above the water table.

(geology after Hogenson and Foxworthy, 1965)

Legend for Figure 4.

ductivity of the older rocks and the differences in the horizontal and vertical hydraulic conductivities of the Columbia River Basalt.

Superimposed on this regional system are intermediate and local ground-water flow systems. The Cascade foothills and other isolated hills bordering and within the study area may be sources of recharge to the intermediate flow system. Ground-water movement in the intermediate system probably takes place in the upper portion of the previously described Columbia River Basalt and the Sandy River Mudstone, as well as in the deeper portions of the fluvial sediments of the Troutdale Formation. Major surface drains receiving ground water from the regional and intermediate flow systems are the Sandy, Willamette, Clackamas, and Columbia Rivers.

Within the study area, a local ground-water flow system can also be outlined. A local ground-water divide is formed by coalescing ground-water mounds under Mt. Tabor, Kelly, Powell, and Grant Buttes. Precipitation is the major natural source of recharge to the local flow system. The ground-water divide is underlain by the previously described Boring Lava and associated remnants of the Troutdale Formation. The generally low hydraulic conductivity of the lava results in a great deal of surface runoff to the adjoining terrace. Much of the runoff toward the north apparently infiltrates into the fluviolacustrine materials as well

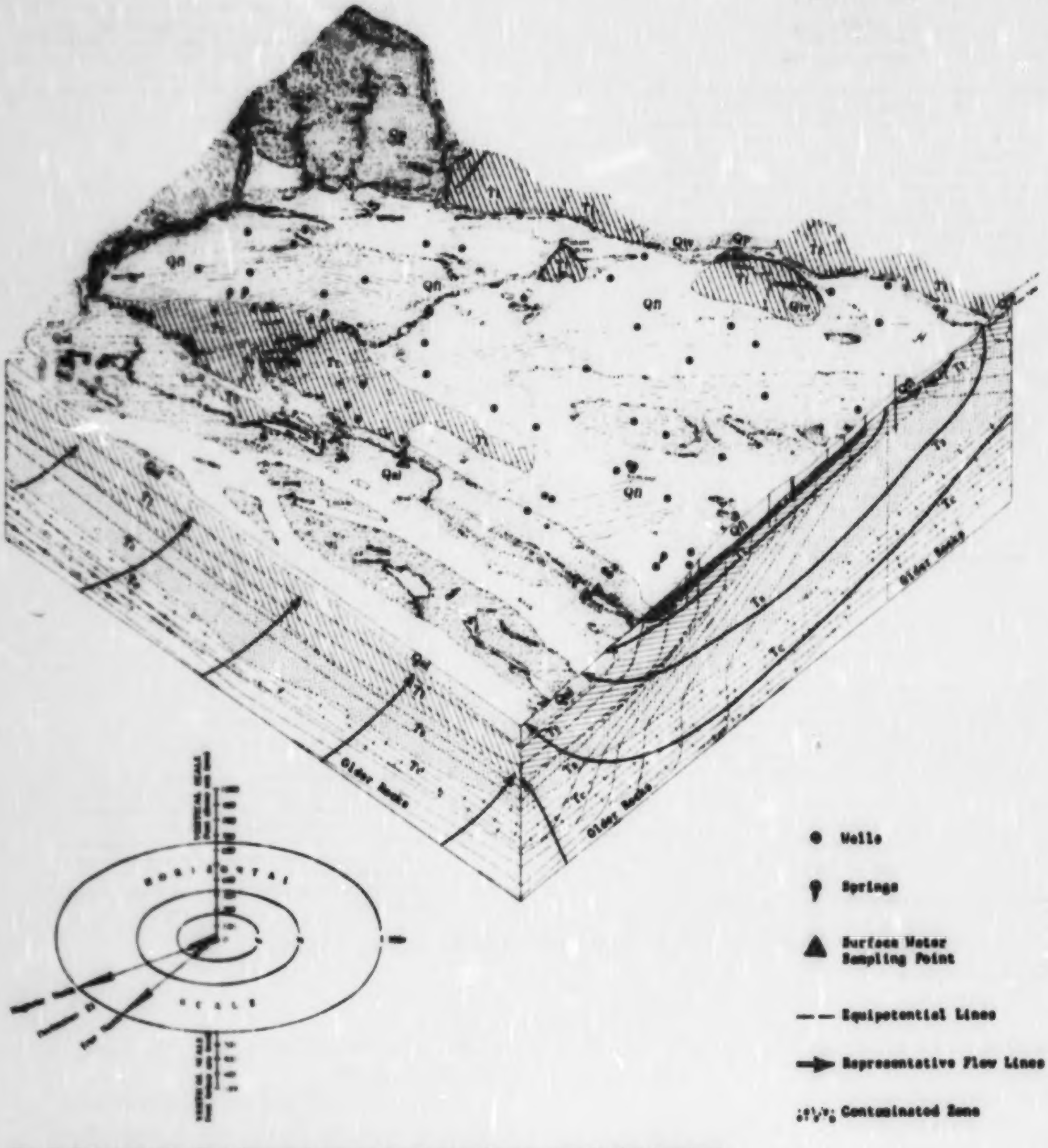
Qn
Qr
Qal
Tt
Tc
Older Rocks
HORIZONTAL
SCALE
Wells
Springs
Surface Water Sampling Point
Equipotential Lines
Representative Flow Lines
Contaminated Zone

Fig. 5. Representative flow lines and contaminated ground-water zone in East Portland.

as the Troutdale Formation underlying the terrace and is a source of recharge to the local flow system. Flow from these recharge areas is directed downward and away from this divide toward Johnson Creek on the south and the Portland terraces and Columbia Slough South Arm on the north. Johnson Creek may provide some recharge to the ground-water flow system. Most local flow is apparently restricted to the saturated portions of the fluviolacustrine materials and the upper part of the Troutdale Formation.

A few representative flow lines have been added to the ends of the basic isometric diagram of the study area on Figure 5. These lines are added in order to qualitatively show the relative directions of ground-water movement in the area. Contaminated ground-water zones are also outlined on this Figure.

Hogenson and Foxworthy (1965) have also described some perched ground-water bodies within the unsaturated zone of the fluviolacustrine material and the Troutdale Formation. Other presumably perched ground-water discharges in springs and seeps in the Boring Lava at several of the buttes in the area.

Many authors, recently including Schwartz and Domenico (1973), have discussed natural water quality patterns in ground-water flow systems. Hughes and Cartwright (1972) generally, and Freeze (1972) more specifically, have pointed out some of the ramifications of waste disposal relative to ground-water flow systems.

Bouma *et al.* (1972) and Dudley and Stephenson (1973) have outlined some water quality problems associated with the subsurface disposal of domestic wastes. Their studies, like most others, are primarily concerned with waste disposal in areas with shallow water tables and/or high hydraulic conductivities. They have pointed out the practicality of using nitrate concentrations as a measure of chemical contamination resulting from the subsurface disposal of domestic wastes. Domestic sewage is often characterized by high concentrations of nitrogen compounds including ammonia, organic nitrogen, and minor amounts of nitrate and nitrite. However, during the disposal and percolation of the effluent through unsaturated aerobic materials, rapid nitrification of the effluent takes place and that effluent reaching the ground-water table contains nitrogen almost exclusively as nitrate. Nitrogen serves as a good tracer because it is not generally susceptible to hydrogeochemical retardation, such as adsorption by clays; it mixes well; and it travels with ground water. Therefore, the nitrate content of the ground water can be used as an indicator of its degree of contamination.

Extensive development and its attendant disruption of natural drainage, paving of recharge areas, and subsurface disposal of wastes has resulted in some changes in the water quality within the study area. In 1965 it was estimated that 8 mgd (34,400 m^3/day) of domestic waste water was being disposed of via subsurface systems in the study area (Moffatt and Taylor, 1965). Since that time, there has been an increase in population in the area and perhaps as much as 10 mgd (38,000 m^3/day) of waste water is disposed of in subsurface systems. These disposal systems include standard septic tank and drainfields, seepage beds, and cesspools. Perhaps 80 percent of the systems are cesspools (see Figure 2). The cesspool disposal in the fluviolacustrine deposits results in very little loss of the waste water to evapotranspiration and consequently most of the liquid percolates downward as local recharge to the water table. This takes place even though the depth to water ranges from 100 to 200 feet (30 to 60 m) in the terrace area. As this contaminated local recharge reaches the water table, it migrates a short distance downwards, through the water table, and then merges with the local flow system. The depth to which the contaminated recharge will penetrate the water table is primarily dependent upon its hydraulic potential and the vertical hydraulic conductivity of the substrata. From this point the primary means of movement for the contaminated recharge is convective transfer, that is with the ground water. Some dispersion of the contaminant can be expected as it randomly interacts with particles in its flow path.

In the study area, it appears that only those wells which tap the upper portions of the saturated zone, local flow system, have significant nitrate contamination. This indicates that as a result of the position of the local flow system above the deeper intermediate and regional systems and the vertical/horizontal differences in hydraulic conductivity, the contaminated ground water is effectively buoyed up. Figure 6 is a plot of the elevation of the

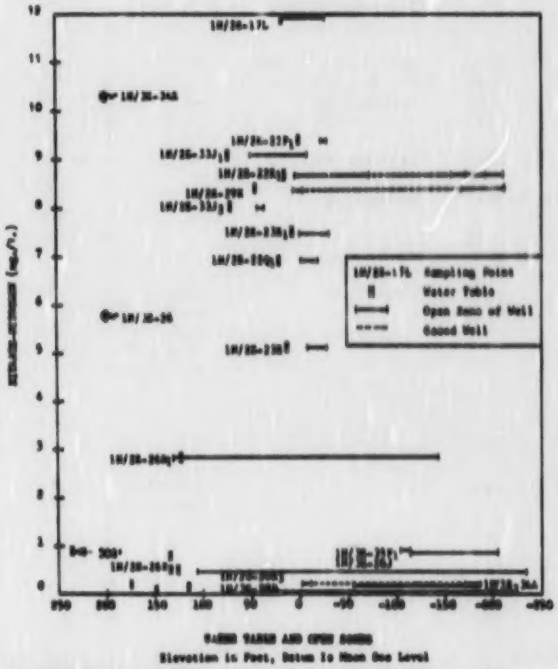

Fig. 6. Nitrate-nitrogen concentrations relative to water table and open-zone elevations in selected wells and springs, July 1974.

Table 1. East Portland Water Quality Data

WELL	OWNER	SOURCE[1]	LABORATORY[2]	DATE	TEMPERATURE °C	pH	CONDUCTANCE (uc mho/cm)	TOTAL DISSOLVED SOLIDS[3]	ALKALINITY (Total as $CaCO_3$)	HARDNESS[4] (as $CaCO_3$)	CHLORIDES[5]	PHOSPHATES (Soluble Ortho)	SULFATES[6]	NITRATE-NITROGEN[7]
1N/2E-17L	Calcagno	Well	a	7/19/74	13.5	7.0	285	206	53	90.1	7.3	0.33	14.5	11.86
$22P_1$	Hopwood	Well	a	7/19/74	12.0	7.1	248	180	47	74.4	6.8	0.30	10.6	9.34
$22Q_1$	Parkrose #1	Well	a	3/3/55	-	7.1	-	195	47	83.0	7.5	0.30	8.5	-
			a	3/9/55	-	7.1	-	195	-	135.0	7.0	-	8.5	-
			b	12/8/58	-	6.9	-	179*	57	70.0	8.2	-	7.0	-
			a	7/17/74	14.0	7.4	260	190	41	48.3	7.8	0.48	3.6	6.89
$22R_1$	Freemont School	Well	a	7/18/74	12.5	7.2	248	194	47	78.1	6.2	0.28	11.2	8.64
$23E_1$	Parkrose #2	Well	c	3/16/72	-	7.3	-	188	54	27.0	11.0	-	14.0	5.40
			a	7/17/74	12.0	7.6	254	190	45	74.8	7.3	0.35	11.7	7.45
23E	Parkrose #3	Well	a	7/17/74	12.0	7.2	248	189	44	76.0	6.8	0.34	12.1	5.10
$26R_1$	Richland #1	Well	a	10/27/60	-	7.9	165	143*	81	88.2	3.4	0.32	2.2	0.11
			a	3/10/71	-	7.2	144	129*	73	68.2	2.2	0.48	3.4	1.50
			a	7/16/74	12.0	7.4	206	-	72	72.3	2.1	0.52	2.5	2.83
$26R_2$	Richland #2	Well	d	4/22/58	11.1	7.2	167	151	101	72.0	2.0	-	4.1	0.00
			a	10/27/60	-	8.0	190	148	96	91.2	3.6	0.41	2.2	0.10
			a	3/10/71	-	7.4	165	130*	89	75.2	1.9	0.56	2.5	0.24
			a	7/16/74	12.0	7.8	225	142	92	77.7	1.6	0.66	1.4	0.44
$26R_3$	Richland #3	Well	a	10/27/60	-	8.0	191	142	96	92.0	4.2	0.28	1.4	0.15
			a	3/10/71	-	7.9	182	129*	102	82.0	2.0	0.46	3.4	0.17
			a	7/16/74	13.0	8.0	244	142	103	83.9	3.1	0.47	1.5	0.16
$26R_4$	Richland #4 (Abandoned)	Well	a	10/27/60	-	8.0	162	133	71	72.2	4.2	0.28	6.0	0.60
29K	City of Portland Bureau of Parks	Well	a	7/19/74	12.5	7.1	267	192	55	88.8	5.2	0.25	15.4	8.36
$33J_1$	Russellville #1	Well	a	1/5/66	-	7.3	210	204*	49	85.0	7.4	0.58	6.5	5.70
			a	7/18/74	13.0	7.5	279	213	63	93.4	5.7	0.50	8.7	9.06
$33J_2$	Russellville #2	Well	a	1/5/66	-	6.9	205	184*	53	83.4	6.3	0.69	5.5	4.70
			a	7/18/74	12.5	7.3	279	194	61	90.5	6.2	0.30	9.2	8.00
$1N/3E-21G_1$	Latter Day Saints	Well	d	6/7/54	-	7.4	423	281	231	163.0	9.0	-	20.0	1.20
$23B_1$	Bonneville Power Ad.	Well	d	6/7/54	17.2	7.8	726	454	132	158.0	156.0	-	7.8	0.40
$23H_1$	Reynolds Metal Co. (4)	Well	d	6/7/54	12.2	-	184	152	87	67.0	11.0	-	4.8	1.00
$23K_1$	Reynolds Metal Co. (12)	Well	e	9/2/52	-	8.0	-	153	-	34.0	6.0	-	-	-
26	Troutdale Spring	Spring	a	2/16/61	-	7.9	155	151	35	68.9	10.5	0.12	12.4	3.60
			a	1/5/66	-	7.4	169	194*	28	57.0	7.3	0.29	9.0	5.70
			a	7/16/74	12.0	7.1	213	152	40	61.2	4.7	0.30	11.6	5.74
$26N_1$	Multnomah Co. Farm	Well	d	2/2/58	12.2	7.9	182	130	106	78.0	2.2	-	1.6	3.30
$34D_1$	Multnomah Kennel Club	Well	d	5/5/58	14.4	7.9	182	155	115	73.0	2.0	-	3.3	0.00
$27M_1$	Fairview #3	Well	a	2/14/73	-	7.8	229	147*	94	87.4	2.1	0.17	2.6	0.00
28R	Fairview #4	Well	a	2/16/73	-	7.7	222	150*	93	82.0	2.1	0.10	3.5	0.03
			a	7/16/74	13.0	8.0	244	144	101	84.3	2.6	0.38	1.9	0.06
28J	Fairview #5	Well	c	6/18/73	-	7.7	-	170	95	-	4.5	-	2.0	0.82
			a	7/16/74	14.0	8.2	241	147	100	84.7	2.1	0.31	1.2	0.09
1N/3E-34A	Woodvillage #1	Well	a	6/16/54	-	8.1	-	144*	101	79.0	1.9	0.50	2.4	-
			a	1/5/66	-	7.6	189	166*	77	77.4	4.9	0.53	1.0	0.02
			a	7/16/74	13.5	7.9	231	141	95	80.6	2.6	0.50	1.4	0.20
35F	Woodvillage #2	Well	c	12/30/69	-	8.1	-	120	101	74.6	3.7	-	3.4	0.25
			a	7/16/74	13.0	8.0	238	123	91	74.0	3.1	0.10	2.5	0.90
34E	Kennel Club	Spring	a	7/19/74	18.5	8.0	211	157	26	61.6	3.6	0.02	12.1	10.30
1N/1E-13C		South	a	8/18/71	20.5	-	-	-	-	-	-	-	-	-
		Arm	a	5/2/72	-	-	261	-	-	-	-	<0.01	-	4.20
		Slough @	a	6/19/72	20.0	8.2	259	234*	92	119.5	6.4	0.01	22.2	3.60
		N.E.33rd	a	7/5/72	21.0	8.5	324	236*	90	122.1	7.5	0.02	21.1	5.90
			a	8/2/72	18.0	6.9	320	235*	88	108.1	6.1	0.39	18.6	3.90
			a	9/12/72	17.0	7.6	324	233*	86	116.8	7.3	0.03	24.6	3.60
			a	11/17/72	10.0	7.1	273	-	-	-	5.0	0.19	-	6.00
			a	9/4/73	19.0	7.6	325	233*	93	116.0	8.2	<0.01	22.2	4.50
			a	7/18/74	17.0	7.1	322	209	85	113.2	4.7	0.04	16.4	4.00
1N/2E-14N		Columbia	a	8/18/71	22.0	6.9	183	199*	73	76.0	5.2	<0.01	11.1	1.40
		Slough @	a	5/2/72	15.0	6.9	206	166*	61	72.0	4.9	0.01	10.8	2.40
		N.E.	a	6/19/72	19.5	7.6	192	183*	69	87.3	7.8	0.05	13.3	2.90
		122nd	a	7/5/72	-	-	-	-	-	-	-	-	-	-
			a	8/2/72	20.0	7.1	230	192*	78	75.1	5.5	0.09	10.5	0.80
			a	9/12/72	16.0	7.1	236	200*	71	77.2	7.0	0.12	11.2	1.10
			a	11/17/72	-	-	200	-	-	-	-	-	-	-
			a	9/4/73	21.0	7.5	208	191*	65	69.2	6.9	0.02	9.4	1.60
			a	7/18/74	18.0	7.1	223	130	44	72.3	4.2	0.03	5.4	1.71
1N/2E-17G		South	a	8/18/71	20.0	7.3	-	-	-	-	-	-	-	-
		Arm	a	5/2/72	17.0	7.1	292	238*	72	95.8	9.0	0.01	17.3	5.30
		Slough @	a	6/19/72	21.0	7.8	-	-	-	-	-	-	-	-
		N.E.	a	7/5/72	22.0	8.1	304	224*	76	101.0	10.1	0.06	15.3	6.60
		Alderwood	a	8/2/72	17.0	7.1	259	215*	72	89.3	9.2	0.29	15.9	5.50
		Drive	a	9/12/72	15.0	7.0	293	218*	68	93.7	8.7	0.26	15.0	4.40

Table 1. (continued)

WELL	OWNER	SOURCE[1]	LABORATORY[2]	DATE	TEMPERATURE °C	pH	CONDUCTANCE (ac mho/cm)	TOTAL DISSOLVED SOLIDS[3]	ALKALINITY (Total as $CaCO_3$)	HARDNESS[4] (as $CaCO_3$)	CHLORIDES[5]	PHOSPHATES (Soluble Ortho)	SULFATES[6]	NITRATE-NITROGEN[7]
			a	11/17/72	-	-	-	-	-	89.7	-	-	-	-
			a	9/4/73	18.0	7.0	293	212*	70	-	10.3	0.11	15.4	6.80
			a	7/18/74	17.5	6.9	298	195	70	91.3	7.8	0.23	11.3	6.89
1N/2E-22D		South	a	8/18/71	14.0	6.7	195	188*	46	74.9	6.6	0.16	12.7	5.30
		Arm	a	5/2/72	13.0	6.5	225	173*	49	74.2	6.5	0.29	11.9	5.60
		Slough. @	a	6/19/72	14.0	6.9	190	171*	50	76.3	7.0	0.24	13.3	3.50
		N.E.	a	7/5/72	-	-	-	-	-	-	-	-	-	-
		122nd	a	8/2/72	14.0	6.8	228	198*	49	81.0	7.6	0.33	21.6	5.10
			a	9/12/72	12.0	6.3	257	193*	43	79.2	12.4	0.25	13.8	3.60
			a	11/17/72	11.0	6.4	204	-	-	-	6.8	0.33	-	7.00
			a	9/4/73	15.0	6.4	236	185*	50	72.4	9.1	0.17	12.6	7.20
			a	7/18/74	14.0	6.6	242	181	47	74.0	5.7	0.31	8.7	8.50
1N/3E-20N		Columbia	a	8/18/71	20.0	7.5	200	205*	80	78.8	6.8	<0.01	8.8	0.64
		Slough @	a	5/2/72	15.0	7.1	190	166*	54	64.8	4.7	0.04	10.8	2.00
		N.E.	a	6/19/72	18.5	7.4	181	178*	54	78.7	5.6	0.05	9.6	1.20
		185th	a	7/5/72	-	-	-	-	-	-	-	0.04	-	-
			a	8/2/72	19.0	7.1	242	190*	85	79.9	6.1	-	8.6	1.00
			a	9/12/72	17.0	7.6	238	220*	78	84.8	6.2	0.20	9.4	0.61
			a	11/17/72	9.0	7.1	188	-	-	-	4.7	0.02	-	2.30
			a	9/4/73	20.0	7.1	216	178*	74	70.8	7.3	0.11	9.7	0.87
			a	7/18/74	20.0	8.6	217	107	72	73.6	4.2	0.04	5.2	1.14

1. w - well; s - spring; sl - slough
2. a - Department of Environmental Quality; b - Pittsburg Testing; c - Charlton Lab; d - U. S. Geological Survey; e - Reynolds Metal Co.
3. U.S. Public Health recommended maximum 500 mg./l.; total solids where *
4. Noncarbonate where *
5. U.S. Public Health recommended maximum 250 mg./l.
6. U.S. Public Health recommended maximum 250 mg./l.
7. U.S. Public Health maximum allowable 10 mg./l.

open zone or zones of some wells in the study area versus the NO_3-N concentrations of water samples collected during July of 1974. It appears that those wells which are in the unsewered portion of the study area, developing water primarily from the upper portion of the local flow system, are significantly higher in NO_3-N, that is having concentrations above 5 milligrams per liter (mg/l). Samples from these wells ranged as high as 11.86 mg/l of NO_3-N. This is in excess of the Public Health Service maximum allowable concentration for drinking water of 10 mg/l of NO_3-N. On the other hand, wells from the unsewered areas and deeper wells, either not developing water from the upper portion of the flow system and/or mixing water from deeper portions of the aquifer generally have NO_3-N concentrations of less than 3 mg/l and most are less than 1 mg/l (see Figure 6 and Table 1).

Other water quality parameters were also considered in the study area. Figure 7 is a plot of nitrate-nitrogen versus sulphate ion concentrations in spring and well-water samples. Although more data points at particular sampling stations are necessary for valid statistical analysis, a general trend showing increased sulphate concentrations with increased NO_3-N concentrations is apparent. Soluble orthophosphate ion concentrations were also measured in well, spring, and surface-water samples. However, the susceptibility of the phosphate ions to sorption has apparently resulted in low levels of this constituent.

Some sampling points outside the unsewered area shown on Figure 3 have also been relatively high in NO_3-N concentrations. The most obvious of these are the Troutdale and Kennel Club springs, 1N/3E-26 and 1N/3E-34E, respectively. The Troutdale spring is immediately downgradient from a small area, about one square mile, which

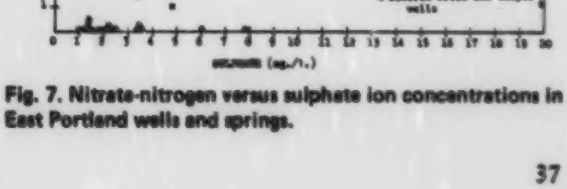

Fig. 7. Nitrate-nitrogen versus sulphate ion concentrations in East Portland wells and springs.

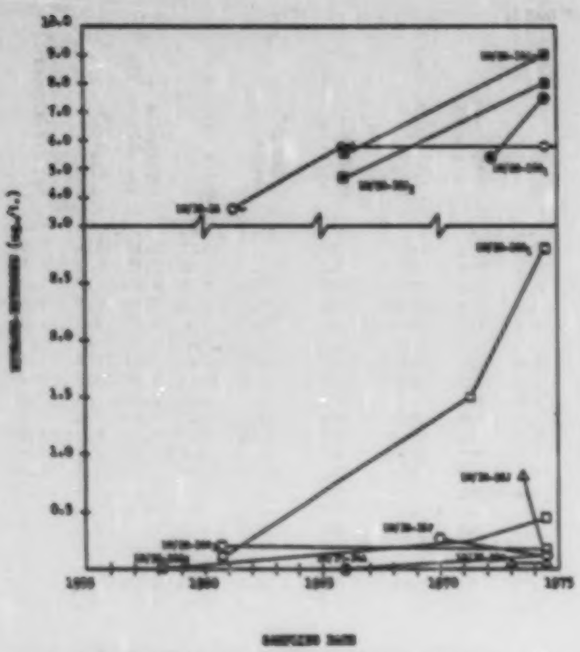

Fig. 8. Trend of temporal changes in nitrate-nitrogen concentrations.

has been sewered in the past 2 to 5 years. Figure 8 shows that the NO_3-N concentration in samples taken from the spring did not increase significantly between the 1966 and 1974 sampling dates. The Kennel Club spring is in a small as yet unsewered, but proposed to soon be sewered, area. Contamination problems may be complicated in these areas by the previously mentioned locally perched ground-water bodies described by Hogenson and Foxworthy (1965).

Although abundant data is not available, there appears to be a temporal change or historic increase in the NO_3-N content of the ground water in the study area. Figure 8 shows this increase graphically. There are not sufficient data points to quantify the contaminant increase, but the trend is apparent. Water samples from shallow wells in the unsewered area continue to increase in NO_3-N concentrations while the wells outside the unsewered area, deeper wells, and/or wells developing from several aquifers remain relatively low in NO_3-N content.

COLUMBIA SLOUGH SYSTEM

As described earlier, the Columbia River is a main surface drain for the regional and intermediate ground-water flow systems. Columbia Slough and its South Arm receive recharge not only from the Columbia River and bank storage, but also from the ground-water flow system. The dynamic hydraulic balance between the river, slough, and ground-water flow system results in seasonal fluctuations in the spring discharge. Innumerable small seeps and springs with measured discharges ranging from less than one to about 700 gpm (0.06 to 44 l/sec) are located along the sloughs.

South Arm Slough is situated upgradient from the Columbia Slough, with respect to the water table. As such it acts as a cutoff or interceptor drain to the upper portion of the water table and picks up much of the shallow local ground-water discharge. This is reflected in the water quality data. During the most recent, July 1974, sampling period, 9 well-water samples apparently taken from the upper portion of the water table in the unsewered area had NO_3-N concentrations ranging from 5.1 to 11.86 mg/l and averaging 8.3 mg/l. Six samples taken from the deeper water wells in the unsewered area and from the sewered area ranged from 0.06 to 0.90 mg/l of NO_3-N with a mean value of 0.31 mg/l. Three samples taken from South Arm ranged from 4.7 to 7.8 mg/l of NO_3-N with a mean value of 6.1 mg/l. At the same time 2 samples taken from the downgradient Columbia Slough had concentrations of 1.14 and 1.71 mg/l. The distance between the South Arm and Columbia Slough sampling points is only about 1,000 feet (300 m) (see Figure 4).

CONCLUSIONS AND RECOMMENDATIONS

Subsurface disposal of domestic waste in central Multnomah County has contaminated the ground-water resource. Nitrate-nitrogen, one of the end products of decomposed domestic waste, was found to be significantly higher in content within the unsewered area than in adjacent sewered areas. This was particularly apparent in wells which develop water from only the upper portion of the saturated zone. A historic increase in the NO_3-N concentration of the ground water in the unsewered area is apparent.

This study determined that the subsurface disposal of waste also affected the quality of surface water adjacent to the study area. South Arm Slough, whose primary source is shallow ground-water discharge, was also found to be significantly high in NO_3-N content, especially in those areas downgradient from the unsewered area.

Sewerage of the area is imperative if the quality of the ground water is to be maintained or improved. As an interim precaution, water wells developing drinking water from the upper portion of the aquifer should mix contaminated well water with water having a relatively low NO_3-N content.

This can be accomplished by adding imported water prior to its distribution or deepening wells in order to mix low NO_3-N water from the uncontaminated portion of the saturated zone with shallower contaminated ground water.

ACKNOWLEDGMENTS

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DISCUSSION

The following questions were answered by H. R. Sweet after delivering his talk entitled "Subsurface Sewage Disposal and Contamination of Ground Water in East Portland, Oregon."

Q. by Rein Laak. *Was surface runoff evaluated?*

A. On the isometric block diagrams I pointed out that there is a paucity of surface runoff from the terrace area, primarily because of the high hydraulic conductivity of the fluviolacustrine materials underlying the terrace. Pavement runoff which may have affected the NO_3-N content in the study area of the slough system was not a factor because all surveys were conducted under dry weather conditions.

Q. by R. G. Knight. *What was the difference between horizontal and vertical permeabilities?*

A. Because of the stratification in the fluviolacustrine materials and in the Troutdale formation, it does not seem unreasonable to assume that the horizontal permeability or hydraulic conductivity is at least an order of magnitude greater than the vertical. In the deeper Columbia River Group, this difference may be as great as several orders of magnitude.

Q. by Dennis Gray. *Were cesspools used without septic tanks?*

A. Generally, yes.

Q. by Stephen Ragone. *What conclusive studies can you cite that show nitrogen in excess of 10 mg/l (as N) is a health hazard?*

A. The U.S.P.H.S. established 10 mg/l NO_3-N as the maximum allowable limit for drinking water because of its potential health hazard to infants. For further reference to the use of this limit and the rationale behind it, I would suggest: Winton, Tardiff, and McCabe, 1971, Nitrate in Drinking Water: Feb., Jour. A.W.W.A., pp. 95-99.

Q. by John Wilson. *Is 8 mg/l NO_3-N high? Do you need to import water to dilute concentrations this low?*

A. The title of our paper indicates contamination, not pollution. In this case, 8 mg/l is high with respect to background levels of less than 1 mg/l. However, our main point is that there is a temporal increase in NO_3-N concentrations in the area and we hope that this increase will be halted before a "pollution" problem develops. The second part of the question deals with imported water and dilution. Low NO_3-N surface water is presently imported into the Portland area. Also, it was pointed out that water from deeper portions of the aquifer is low in NO_3-N and suitable for dilution. Therefore, we are not proposing the development of a new water system for the area but some simple changes in plumbing, which will alleviate a problem should the temporal increase in NO_3-N continue.

Q. by Fred Cratus. *Is cesspool technique the problem or are you saying that all on-site systems are not adequate? If other on-site designs do a good job, what is the economics of on-site reclamation vs. central sewer?*

A. The cesspool technique ultimately allows all products of waste decomposition to enter the local flow system. NO_3-N, one of these waste products, has reached high concentrations within the study area because of the high population density. Other on-site systems, i.e. septic tanks and drainfields, are probably more efficient in removing decomposition products through evapotranspiration and root absorption of nutrients. However, the current density of development in the area precludes the installation of septic tank and drainfield systems as a solution to the problem. Preservation of the ground-water resource as a potable water supply requires installation of an area-wide sewerage system.

Q. by Gary G. Small. *What method was used to analyse NO_3-N and what was the time delay between the sampling time and the time of analyses?*

A. In many of the older samples shown in Table 1 of the paper we are not sure of the method of analysis for NO_3-N. However, the more recent samples were analyzed using the Brucine method as outlined in the 13th edition of *Standard Methods for the Examination of Water and Waste Water.* The last set of samples used in this paper was collected between July 16 and 19, 1974, and all samples were analyzed on July 19, 1974. All samples were refrigerated between time of collection and analysis.

Sampling of Variable, Waste-Migration Patterns in Ground Water[a]

by K. E. Childs[b], S. B. Upchurch[c] and B. Ellis[d]

ABSTRACT

A survey of waste-migration patterns from septic-tank/tile-field systems surrounding Houghton Lake, Michigan indicates that sampling plans designed to detect and quantify waste migration in ground water should be predicated on the concept that the waste plume may be complex and that the plume may not follow regional, ground-water flow. The waste-migration plumes at Houghton Lake range from simple, multichemical plumes that move with regional flow to complex plumes that bifurcate, that show different migration patterns for different chemicals, and that move up the regional gradient for short distances. The complexity of these patterns is attributed to a combination of the following system properties: loading rate and recharge at the waste source, local hydrology, chemical-adsorption capacity of the soil, soil microbiology, regolith texture and fabric, and proximity to other waste sources. Based on the observed patterns, it is suggested that observation wells be placed so that an in-depth, 3-dimensional array of samples can be obtained. The wells should be of sufficient depth to insure that deep-moving plumes can be detected and, if the actual, vertical-migration pattern is of importance, the wells should allow collection of water samples at a number of depths. The waste-migration pattern should be monitored throughout the year in anticipation of vertical movement of the plume axis during periods of surface recharge. If more than one chemical is of interest, then it is unsafe to assume that an index chemical, such as chlorides, demonstrates the migration of the other chemicals and analyses must be run for the other chemicals.

(Key words: waste migration, septic tanks, ground-water contamination).

(Running head: waste-migration patterns).

INTRODUCTION

The general pattern of waste migration within the ground-water regime is assumed by many to be characterized by the single-plume model. This characterization portrays a homogeneous mass (plume) of waste that is migrating in the direction of net ground-water movement, that is undergoing only dilution with distance, and that is transported from a point source to an area of ground-water discharge, such as a lake or stream. Ground-water studies usually commence with the construction of a regional, piezometric map, which is the basis for locating an array of sampling (observation) wells between the waste source and the area of suspected ground-water discharge. Frequently, these wells are positioned at a common depth below the top of the saturated zone. To obtain background-concentration data, wells are placed nearby and upgradient from the waste source. The water samples collected from these observation wells are usually analyzed for a single constituent, or a limited number of constituents, under the assumption that most waste chemicals move along a common axis. By this model, therefore, the presence of a single constituent implies the presence, or possible presence, of other constituents of interest. The severity of ground-water contamination is evaluated by comparison with the data obtained from the background concentrations. The single-plume model and related interpretations have been widely used in the interpretation of ground-water contamination from various types of sources (e.g., Deutsch, 1961; Childs, 1970; Bernhart, 1973; Dudley, 1973; Ellis and Childs, 1973; and Bouwer, 1974).

There is good evidence to indicate that the single-plume model is useful only to demonstrate that there is a potential for ground-water contamination. If data are required to show the specific behavior of multichemical wastes, then a single plume cannot be assumed and much more extensive sampling in a 3-dimensional array is required.

Procedures for defining waste-migration patterns, utilizing the single-plume model, were developed during a study (Ellis and Childs, 1973)

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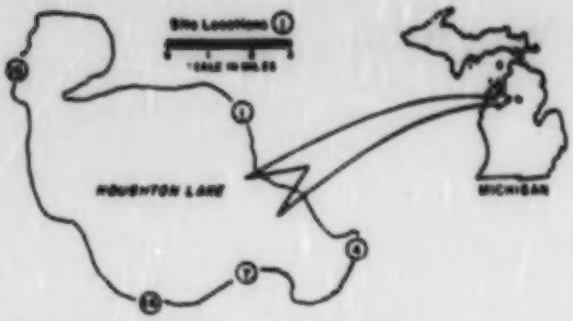

Fig. 1. Location of sample sites at Houghton Lake, Michigan.

of the migration of septic-tank wastes around the perimeter of Houghton Lake, Michigan (Figure 1). An important outcome of this study was the awareness that data collected under the assumption of a single-plume model frequently do not allow an accurate characterization of system behavior. The purpose of this paper is to provide evidence that necessitates a model which characterizes the complex, dynamic migration of multichemical waste from a point source. This information can be expanded and utilized to develop more realistic ground-water sampling programs.

STUDY AREA

Geological Setting

Houghton Lake has 30 miles of shoreline, a surface of 19,600 acres, and an average depth of 10 feet. The lake is eutrophic and appears to be undergoing phosphorus enrichment (Pecor, Novy, Childs, and Powers, 1973; Pecor, Novey, Tierney, and VanLandingham, 1973). The lake was chosen as a study area because of a high population density (11,000 permanent residents), because of its importance as a recreation resource, and because of a suspicion, based on the eutrophic condition of the lake, that the lake was receiving large inputs of phosphorus from septic-tank systems via ground water.

Houghton Lake is a large, shallow kettle lake (Kelley, 1956). Approximately 80 percent of the soils of the area immediately surrounding the lake are developed on the outwash that surrounded the stranded ice block. The other 20 percent are developed on recessional and ground moraines that border the lake to the south and southwest. Based on geologic considerations, the area has been mapped for septic-tank-use suitability (Childs, 1973; Ellis and Childs, 1973; and Tilmann *et al.*, 1974). Approximately one-third of the lake shore study area was considered to be suitable for septic-tank use. The remaining lake shore is marginal to unsuitable because the glacial deposits have low nutrient-adsorption capacities or low or excessive permeabilities.

The original waste-migration study (Childs, 1973) investigated waste movement from 19 septic-tank sites located within ½ mile of Houghton Lake. The sites were located to include all of the soil types along the lake shore. This paper presents data from 5 test sites (Figure 1) that show the greatest variability and complexity in waste migration. The 5 sites are located on 2 soil types (Newton Loamy Sand, Rubicon Sand; Table 1) which comprise approximately 55 percent of the lake shore. The 2 soil types are developed on outwash sediments, and are distinct in physical and chemical properties. According to the septic-tank-use suitability surveys, these soil types range from fair to excellent for this use.

Table 1. (from Schneider & Erickson, 1972)

Soil Type	*Profile*	*Phosphorus Adsorption Capacity (lbs/acre-ft)*	*Water Holding Capacity (in/ft)*	*Permeability (in/hr)*	*Depth to Water Table (inches)*	*Slope (%)*	*General Soil Description*
Newton Loamy Sand	0-4"–Sand	72	1.01	17	0 to 24"	0 to 2	Consists of a few inches to one foot of black, mucky surface soil over a wet, gray, sandy subsoil.
	4-45"–Loamy Sand	1640	6.79	9			
	45-60"–Sand, Parent Material	550	1.61	23			
		2262					
Rubicon Sand	0-4"–Sand Surface	104		34			Well-drained minimal podzols developed in deep, sandy outwash. Rich in iron, calcium, and aluminum.
	4-45"–Sand-Subsoil	1008	Very Low	44	Approximately 60"	0 to 12	
	45-60"–Sand, Parent Material	1368		86			
		2480					

Climate

The Houghton Lake area is in the northern half of the lower peninsula of Michigan. The area has a mean annual temperature of 41 degrees F, a mean annual precipitation of 27 inches, including an average snowfall of 56 inches, and an annual ground-water recharge such that between 15 and 27 percent of the water entering Houghton Lake is ground water (Childs, 1973; Pecor, Novy, Childs, and Powers, 1973; Swearingen, 1973). The winters are long, and frozen ground prevails from November to March. Occasional freezes may be expected in September and May. Approximately 70 percent of the precipitation occurs as rain from May through October. The remaining 30 percent is snow, the majority of which is stored as snowpack until the spring thaw. Therefore, infiltration is seasonal, with maximum recharge to the surface aquifer occurring with the combination of precipitation and snow melt in the spring. The seasonal recharge implies that flushing of the regolith is also seasonal and that vertical displacement of waste plumes may occur under near-laminar flow conditions.

PROCEDURES

Ground-water and soil samples were collected in the vicinity of operating septic-tank/tile-field systems located within a half mile of the shoreline of Houghton Lake. Four criteria were used to select test-site locations:

1. Loading history—the systems had to have been used by at least 2 full-time residents for a time period of several years.

2. Accessibility—test sites had to be available for the collection of water and soil samples.

3. Soil types—the sites were chosen to be representative of area soil groups.

4. Isolation from other known waste sources.

Ground-water samples were collected through water wells, driven to a maximum depth of 24 feet below the water table. The sampling equipment consisted of a 1¼-inch drive pipe, a pitcher pump, and 24-inch drive points with 18-inch, wound-wire, 10-slot screens. Test wells were driven and pumped in 2-foot intervals. This procedure provided a vertically-stratified set of water samples from the water table to the maximum test depth.

Soil samples were collected above the water table using a soil auger. Soil cores, 10 feet in length and 1 inch in diameter, were collected from the saturated zone by means of a 1-inch plastic tube attached to a vacuum pump (Figure 2). The plastic tube was inserted into the soil, a vacuum applied, and the core retrieved under vacuum. The core was then subsampled in 1-foot intervals.

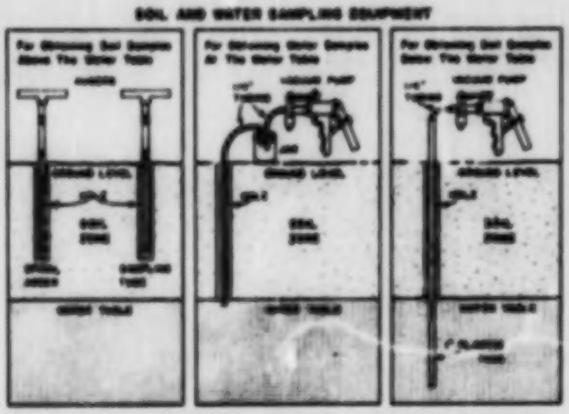

Fig. 2. Diagram showing method of recovering soil samples from below the water table.

All chemical analyses were according to the procedures in *Standard Methods* (American Public Health Association, 1971). The air-dried soil samples were sieved and the fraction finer than 2 millimeters was subjected to phosphorus extraction according to the method outlined in Ellis and Childs (1973). The extraction was accomplished with 0.025 N HCl and 0.03 N NH_4F with a soil to solution ratio of 1:10.

RESULTS

A number of the sites investigated showed anomalous results in comparison with the single-plume model. These anomalies included differential movement of chemicals from a single source, bifurcation of the waste plume, and, in systems where mounding of the water table is extreme, upgradient migration. The following examples demonstrate these phenomena.

Test site 1 (Figure 1) is situated in Rubicon Sand about ½ mile from Houghton Lake. The septic tank/tile field has been used continuously for approximately 15 years by a family of 6. The site is semi-isolated with the nearest adjacent source of wastes over 200 feet away. The soil is homogeneous to the eye. A ground-water table map, based on surveyed elevations, suggests that net ground-water movement is lakeward. The water samples from site 1 were analyzed for chloride, nitrate nitrogen, and phosphorus (expressed as phosphates). Figure 3 shows the vertical configuration of the waste plume in the direction of the lake. Note that nitrates and chlorides extend to depths of at least 20 feet, while

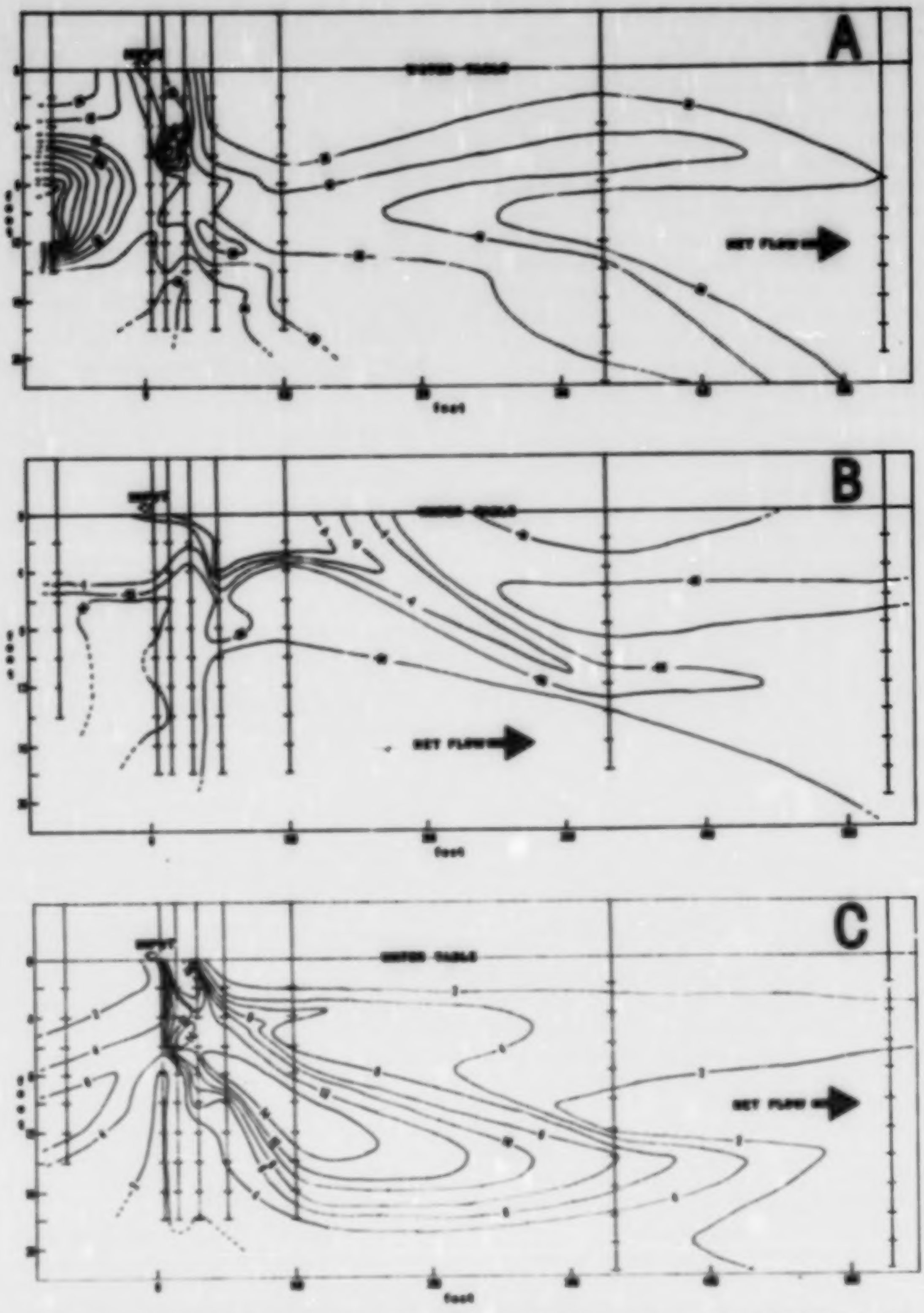

Fig. 3. Cross sections of the waste plume at site 1. A is chlorides, B is phosphorus (expressed as phosphate), and C is nitrates. All concentrations are in parts per million.

phosphorus is more or less confined to the upper 10 feet of the saturated zone. Phosphorus is also much diminished in concentration in the water within 100 feet of the source, which probably reflects the high phosphorus-adsorption capacity and low water-holding capacity of the Rubicon Sand (Table 1). Chloride distribution suggests that there is some contamination of the site from a source upgradient. The magnitude of this chloride plume seems high for a domestic source and may reflect road salting, which is prevalent during the winter months. This conclusion is supported by the distributions of phosphorus and nitrates, which indicate possible upgradient movement of material from the source at site 1. There is indistinct water mounding at the septic system in site 1, so the upgradient movement is most likely due to chemical diffusion. There is no indication as to the cause of the bifurcation of the waste plumes of each chemical. Three possibilities for this bifurcation are variation in loading history from the septic system, seasonal variation in infiltration and ground-water flow, and textural or fabric inhomogeneities in the regolith. Clearly, selection of sample interval in each well, well depth, and well spacing is critical to the interpretation of waste contamination from a site such as site 1.

Sites 4 and 7 (Figure 1) are located on the Newton Loamy Sand within 150 feet of the lake shore. Both sites are characterized by high water tables and sand to loamy sand substrates. The septic systems have been in use for approximately 10 years by families of 6, each. Water samples from these 2 sites were analyzed for phosphorus and nitrates (Figure 4). At each site the waste plume is significant as a comparison with the plume at site 1 (Figure 3), because the waste plumes appear to be confined to the upper 6 feet of the saturated zone. At both sites it is evident that there is phosphorus and nitrate migration into the lake. It is also apparent that phosphorus is equally as mobile as nitrates in these systems. In contrast with site 1, where chlorides are most mobile, nitrates second, and phosphorus is least mobile, these 2 sites dramatize the fact that single constituents cannot be expected to characterize a multichemical system. Within the 19 sites examined, there were cases where each of the 3 chemicals described above was mobile in comparison with the others. These differences in mobility can be related to loading variations, adsorption-capacity variations in different soil types, and differences in reaction kinetics between the 3 chemicals.

Comparison of adsorbed phosphorus in the soil with the dissolved phosphorus in the water of

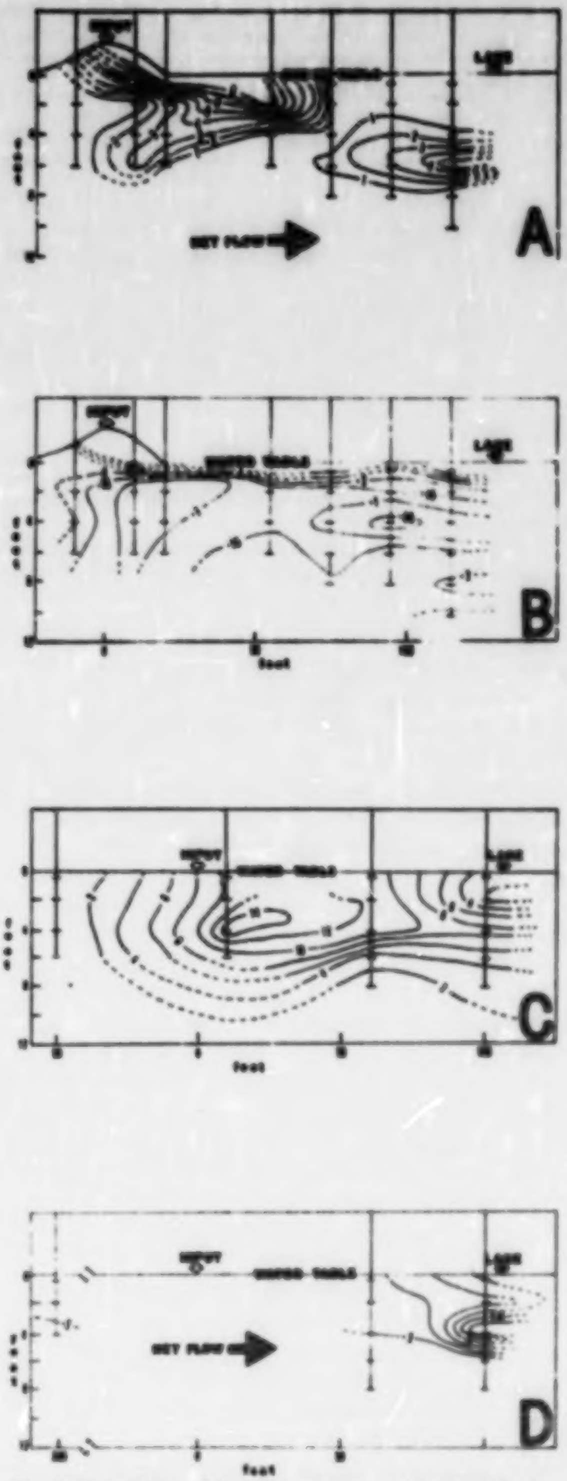

Fig. 4. Comparison of the waste plumes at sites 4 and 7. A and B are phosphorus (expressed as phosphates) and nitrates, respectively, at site 4, while C and D are phosphorus and nitrates, respectively, at site 7. All concentration values are in parts per million.

Table 2. Comparison of Phosphorus (Expressed as ppm Phosphates) in the Soil and Water at Septic Sites 14 and 15. Arrows Indicate Location of Septic Tanks in Relation to Wells. Sample Intervals Vary[1].

Depth from surface	↓ *Site 14*						↓ *Site 15*					
	PO$_4$ on soils	*PO$_4$ in water*	*C.F.*[2]	*PO$_4$ on soils*	*PO$_4$ in water*	*C.F.*[2]	*PO$_4$ on soils*	*PO$_4$ in water*	*C.F.*[2]	*PO$_4$ on soils*	*PO$_4$ in water*	*C.F.*[2]
1	21			39			60			22		
2	15	–	–	51	–	–	52	–	–	84	–	–
3	8	WATER		48	TABLE		79	WATER		87	TABLE	
4	11	2.5	11	63	0.11	490	100	8.0	8.8	86	0.30	270
5	43			44			40			74		
6	76	5.0	15	18	0.02	830	48	4.0	11	48	0.01	3500
7	69			15			37			22		
8	25	9.0	1.9	12	0.04	210	24	0.08	290	16	0.00	infin.
9	10			5			22			14		
10	3	0.20	15	15	0.01	1500	21	0.01	2100	15	0.01	1500
11	–			–			–			–		
12	–	0.01	–	–	0.00	–	–	0.00	–	–	0.00	–

[1] Soil samples were collected every foot below the ground surface; water samples were collected at 2-foot intervals from the water table.

[2] C.F. is the concentration factor and is the weighted ratio of soil-bound phosphates to aqueous. Soil-bound phosphate was weighted by averaging of analyses within each 2-foot interval from which a water sample was taken.

the saturated zone demonstrates one of the possible mechanisms that results in the differential movement of constituents away from a waste source. Test site 14 is a resort owner's home that has been used by a family of 3 for approximately 10 years. Site 15 has been permanently used by a family of 2 for about 20 years. Both sites are located in the Newton Loamy Sand in close proximity to the lake. Chloride, nitrate, and phosphorus data from the 2 sites reveal complex flow of waste chemicals toward the lake. In order to evaluate how effective the soil minerals are in removing phosphorus from the ground water and, thus, causing differential waste migration, phosphorus was stripped from the soil minerals in the test wells at these 2 sites. Table 2 compares the results of the water analyses with those of the soil-bound phosphorus. It is evident that phosphorus is removed from the ground water below the water table, and differential movement is likely to occur. Chlorides, though generally considered conservative, may also be absorbed on clays (Grim, 1968), and nitrates have been shown to be reactive with clays in solution.

Therefore, the differential movement of the 3 chemicals may result from adsorption on soil materials. Again, if a simple-plume model is used, there is a potential for error in sample selection. Note the distribution of concentration factors in the data of Table 2. The concentration factor is the ratio of soil-adsorbed phosphorus to aqueous phosphorus. If simple, linear diffusion and adsorption were to occur in a homogeneous regolith, then the concentration factor would also vary in a linear fashion, with lower ratios near the waste source where adsorption may be retarded or incomplete. Ellis and Childs (1973) have shown that the soils of the Houghton Lake area can be saturated with respect to phosphorus, which will retard adsorption and maintain a low ratio. They found that maximum adsorbed phosphorus in the field was 120 ppm for the Newton Loamy Sand and 135 ppm for the Rubicon Sand. These values compare favorably with maximum loadings determined from Langmuir-isotherm calculations (Newton Loamy Sand–100 ppm, Rubicon Sand–140 ppm). Also, if the rate of loading exceeds the rate of adsorption, a low ratio will result. The data in Table 2 indicate that the concentration ratios are not linear away from the respective sources, so it is evident that either non-uniform adsorption occurs or there are multiple plumes of phosphorus.

DISCUSSION

The above data illustrate some of the complexities that may be encountered in the analysis of waste plumes in ground-water systems. These complexities result from subtle causes, so there appears to be little way in which they may be completely anticipated. A few of the more obvious causative factors are (1) loading rate, (2) recharge at the waste source, (3) local hydrology, (4) chemical-adsorption capacity of soil, (5) soil microbiology, (6) regolith texture and fabric, and (7) proximity to other waste sources.

Loading rate, local recharge, and local *hydrology* may cause variation in the rate of migration and position of the plume axis or axes. Loading rate includes the introduction of waste chemicals through the septic system and associated sources, such as lawn fertilization. Local recharge refers to water introduced to the regolith from the septic system, from drains associated with the home, and from infiltration from the surface in the vicinity of the source. Local hydrology includes sources other than those associated with the septic system and other domestic wastes. These sources include regional drains, surface runoff from paved areas, and, in the case of the sites discussed in this paper, bank storage from streams and lakes. Any, or all of the above can interact to produce upgradient movement of wastes, bifurcation of water masses, and vertical movement of the axes of plumes through time. For example, at Houghton Lake the soil surface is frozen for up to 5 months of the year. During this period, recharge from the surface is retarded and lateral ground-water flow predominates. During the spring thaw and early summer, when rainfall is greatest, there may be maximum infiltration at the surface, which may displace the plume downward. This phenomenon, combined with seasonal use of the septic system and lawn fertilization (Ellis and Childs, 1973), may result in the production of multiple waste plumes and differential chemical migration.

Proximity to other waste sources may have the effect of masking the movement of a waste plume, and it may interfere with the determination of background water quality. The sites selected for discussion in this paper were chosen for their isolation. However, extraneous loading, such as chemicals derived from paved areas and fertilized lawns, may interfere with detailed analysis of a plume in spite of careful site selection (cf., Figures 2, 3). Arrays of observation wells should be 3 dimensional about the suspected waste source, so that unexpected contaminants can be detected and related to their respective sources.

Chemical-adsorption capacity of soil and soil microbiology have the ability to remove chemicals. Chemical-adsorption capacity of the soil includes surface adsorption on all grains, exchange on clay minerals, and adsorption on soil-organic matter. Soil microbes metabolize and fix organic debris. The result of these processes is the immobilization of certain waste chemicals. The data presented herein indicate that this immobilization can occur both above and below the water table (Table 2), thus creating the potential for differential movement of chemicals in a waste plume.

Regolith texture and fabric include the effects of porosity and permeability on fluid movement. The soils discussed in this paper are operationally homogeneous and the underlying, glacial outwash consists of well to moderately well-sorted sands. These strata should be relatively isotropic to fluid flow. However, fabric variations, such as grain orientation, incipient cementation, and bedding, may cause differential flow.

Few of the causative factors discussed above can be anticipated when laying out a sampling plan. This necessitates development of a plan that includes wells arrayed in all directions from the waste source and installed with provisions for sampling at intervals to a depth suitable to insure that the base of the plume or plumes has been intercepted.

CONCLUSIONS AND RECOMMENDATIONS

The constituents in the waste plume are sensitive to regolith chemistry and local hydrology. The 3 chemicals discussed in this paper, chlorides, nitrates, and phosphorus, do not move as a single plume. The 2 non-conservative compounds are removed from the effluent by adsorption on soil materials above and below the water tables. The 3 chemicals migrate downward and laterally at different rates, so there is partitioning of the effluent into several "sub-plumes" that move away from the waste source at different levels and extend laterally for different distances. Since the depth and extent of migration varies between chemicals from site to site, one cannot assume that monitoring of a single constituent allows characterization of the system.

Interpretation of plume migration must include 3-dimensional sample arrays. These arrays will obviate problems associated with identification of incidental sources of contaminants and background water quality.

Since chemical removal by soil particles and microbes emphasizes concentration gradients of non-conservative constituents, substrate samples should be analyzed for determination of net waste migration. The substrate samples provide an integration of the distribution of waste chemicals in a mobile plume, whereas water analyses provide a static and, perhaps, unrealistic view of the configuration of the plume in time. Furthermore, ground-water contamination is commonly expressed in terms of water-quality impairment as a function of distance from the source. This evaluation does not reflect multi-plume waste-model concepts, nor does it reflect the contamination that may be retained (temporarily?) within the regolith. Ground-water studies must consider the relationship that exists between the waste constituents and the regolith. This relationship includes the assimilative capacity of the soil and the total volume of soil available to serve as a filter. Saturation of the soil filter with respect to a constituent that can be adsorbed limits the effectiveness of the filter and encourages waste migration. Thus, loading rate, present quantity of adsorbed chemicals, chemical-adsorption capacity of the soil, and volume of the soil filter, in addition to water quality, should be evaluated in ground-water contamination studies.

The migration patterns for the 3 constituents described herein bifurcate vertically, indicating that the plumes may occupy several levels below the water table with changes in loading rate or water supply, or that the plumes migrate along zones in the regolith that, although they are texturally similar, show subtle differences in fabric that result in slight variations in permeability. These bifurcations indicate that detection of a shallow plume does not negate the existence of other plumes of the same constituent at depth.

Since waste migration is a dynamic response to (1) local and regional hydrology; (2) regolith texture, fabric, chemistry, and microbiology; and (3) loading history; the pattern of waste migration should be correspondingly complex. Therefore, the design of an adequate sampling plan to characterize the movement of wastes away from a source by means of subsurface flow should account for the possibility of the existence of a complex-waste plume. Samples should be taken in a 3-dimensional array about the waste source, even though prior knowledge suggests a preferential flow direction. The nature of the plumes observed at Houghton Lake indicates that water samples should be collected at closely-spaced vertical intervals and at several dates through the year, if the path of waste migration is to be accurately delineated. If background concentrations are to be delineated, samples must be taken deep enough below the water table or far enough away from the waste source to avoid all possibility of contamination by downward-deflected plumes. To avoid incidental contamination by adjacent waste sources, the background water-quality wells should be tied into the sample net laid out around the source and should be placed in all directions from the source. In this way, incidental waste sources can be detected and discounted. When the wells are driven, serial soil samples should be collected and analyzed for texture and, if possible, fabric. The soil samples should also be analyzed for adsorbed chemicals and ultimate adsorption capacity. Finally, the water-quality samples taken through time should be closely correlated to the local climate and hydrological events.

ACKNOWLEDGEMENTS

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DISCUSSION

The following questions were answered by K. E. Childs after delivering his talk entitled "Sampling of Variable, Waste-Migration Patterns in Ground Water."

Q. by D. E. Donaldson. *You speak of phosphorus "adsorption." Could it be adsorbed? There are sorption-desorption reactions with "P."*
A. Adsorption is assumed by the authors of this paper to be the dominant mechanism for removal of phosphorus from solution. Adsorption refers to a chemical or constituent being attached to the surface. Absorption refers to something being trapped internally or within the structure; solid state mineralogy. Sorption is a general term including all mechanisms. Yes, there are sorption-desorption reactions with phosphorus, but we were only concerned with the phosphorus that was attached to the matrix at the time of sample collection.

Q. by H. R. Sweet. *Did you run laboratory adsorption capacities (maximums) on the various soils with respect to NH_4 and PO_4?*
A. Phosphorus adsorption capacities have been run for most Michigan soils, or, at least, for similar soil types. The NH_4 capacities were not established for Michigan soils.

Q. by R. G. Kazmann. *Have you ever looked at the silt or clay content in the soil or aquifer? If so, was the clay montmorillonite or illite?*
A. No, we have not determined quantitatively the clay or silt fraction in the sediments present at the septic-tank test sites. The matrix textures were identified using the existing soil classification system. We estimate the clay fraction to be 5 percent or less and the clay minerals, when present, to be dominantly illite. We believe that the coarse Rubicon sand at site number 1 adsorbed much larger quantities of phosphorus than the fine sand at sites number 4 and 7 because:

(1) Site number 1 soils have a higher percentage of Fe, Al, and Ca which forms insoluble salts with phosphorus.

(2) Waste constituents from site number 1 moved through a vastly larger filter zone, especially when you consider the volume of filter within the zone of saturation.

Q. by Bruce Yare. *How were the water samples (collected every 2 feet) brought to the surface? What was their turbidity? If excessive, what effect did this have on chemical analyses?*
A. All water samples were collected with a pitcher pump after a sufficient quantity had been wasted to ensure that the samples were not contaminated by priming water. All water samples were filtered prior to analyses. At some test sites we attempted to field check water samples, without filtration, for phosphorus by adding a lab pre-mix. The purpose was to get in the field an indication of phosphorus, if present, so we could continue testing or alter testing without waiting for the laboratory results. This plan was not successful because the water samples would frequently contain fine sediments which undoubtedly carried adsorbed phosphorus. The laboratory mix would wash the phosphorus from the fine sediments and produce a blue color indicating the presence of phosphorus. The same water samples, after filtration, would not indicate, other than trace amounts, the presence of phosphorous. Frequently, filtration is a necessary step prior to the analysis of water samples.

Q. by Paul Plummer. *Are home water softeners common to this area? If so, what is a typical hardness?*
A. Water in this area is intermediate in hardness and water softeners are not common. There were no water softeners used at any of the test sites.

Q. by Frank Merrill. *Was there any maintenance performed on the septic tanks? Such as cleaning? Do you feel the septic tanks were overloaded?*
A. There was no maintenance performed on the septic systems prior to the collection of soil and water samples. The systems tested were selected on the basis of heavy loading and, consequently, it is quite likely that many were being used in excess of design capacity.

Q. by Donald Runnells. *Do you have data for nitrogen in soil as compared to nitrogen in water, similar to your phosphorus data?*
A. Nitrogen data for soils is very difficult to obtain and is presently unavailable for Michigan soils.

Will Current Research Answer Today's Problems at the Sanitary Landfill?[a]

by Prof. James C. Warman[b], Dr. Rex K. Rainer[c], and Mr. Alfred S. Chipley[d]

ABSTRACT

Alabama's solid waste management program has been commended repeatedly by the U.S. Environmental Protection Agency for establishing and operating throughout nearly all of the State effective, county-wide, State-approved, rural solid waste collection and disposal systems. The program is administered and regulated by the Division of Solid Waste and Vector Control of the Environmental Health Administration. Collection systems, sanitary landfills, and other parts of the program are rated by the regulatory agency; rating of landfills is used in enforcement. In 1974, 87.0 percent of the 67 counties in Alabama representing 97.0 percent of the total State population of 3,444,000 had total collection and disposal systems.

The two greatest problems in the sanitary landfill program are disposal of hazardous industrial wastes and training of operators; other problems are noted. Current research throughout the nation on ground-water pollution related to sanitary landfills was reviewed to identify expected research results that will help solve the problems.

All the States have either developed or are developing statewide solid waste management plans. The State of Alabama is a leader among the top few States that have passed and have implemented very good legislation in this field. Alabama, in particular, has probably made the most progress of all States in achieving the highest percentage of the State's counties to establish and place in operation State-approved, effective, county-wide, rural solid waste collection and disposal systems.

In the solid waste management field, Alabama's leadership is well-known. The Environmental Protection Agency has repeatedly commended the determination, imagination, self-reliance and the achievement exemplified in the State of Alabama's program. Alabama's sole federally-funded demonstration project, started in 1968 in Chilton County, has been eminently successful. The Chilton County experience is continually cited by environmentalists as a classic example of how much can be accomplished in solid waste management in the rural areas of the nation.

Solid waste management in the State of Alabama is administered by the Division of Solid Waste and Vector Control of the Environmental Health Administration. The Division of Solid Waste and Vector Control has a Director, two professionals, and one clerical worker. The current annual budget from the State is $46,458. The Director's salary and corresponding salary benefits are paid by the Federal Government. The Director's travel and maintenance expenses are paid by the State. Each State is entitled to a 216 grant; however, the proceeds from the grant are reduced by an amount equal to the salary and benefits paid the Director by the Federal Government. Only in the last year has the Division of Solid Waste and Vector Control become a line item in the State budget.

The disposal of radioactive materials is regulated in the State of Alabama by the Radiological Division of the Environmental Health Administration. This Division makes the distinction between low level and intermediate level radioactive wastes and designates approved disposal sites for shipment of the wastes. No commercial radioactive waste disposal sites are operated in Alabama.

The foregoing introduction is given to justify the authors' selection of Alabama's Solid Waste Management program as a reference point to indicate the present state of the art. Further, the thoroughness and meticulous care with which data is kept in Alabama by monitoring results of site selection, operation, leachate characteristics, ground-water effects, and effective equipment and pick-up arrangements provide a meaningful beginning point to predict the potential usefulness of certain research projects currently underway and to identify problems needing further research on sanitary landfills.

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Appendix A contains rating charts used in Alabama. One rating chart is for evaluating solid waste management programs county-wide; the other rating chart is for evaluating solid waste land disposal sites. Note that a point system is included for use in arriving at a numerical total score. The program rating chart is used for general information; however, the site rating chart is used for specific information in the enforcement program.

Once or twice each year, sites and programs are evaluated by inspectors and a copy of the evaluation form is sent to the County Commissioners and the County Health Officer. In the event a substandard operation is determined to exist, a letter with the evaluation form outlines corrective measures recommended. The responsible parties are at the same time notified that the deficient operation will be re-rated within 10-30 days. After re-rating, if unsatisfactory conditions still exist and if no attempt at corrective measures has been undertaken, a stiffer letter is sent and another visit made. In the event of continued inaction, the Attorney General's Office in the State of Alabama is notified for legal action and enforcement. The Attorney General can bring suit. A maximum fine of $500 per day at fault may be levied. At this time, no fines have been levied against municipalities.

The geologic and hydrologic conditions in Alabama vary from terranes of limestone, coal measures, and Piedmont metamorphics to the sands, gravels, and clays of the Coastal Plain. Thus the criteria for sanitary landfill site selection and the protection of ground-water quality must provide concern for a wide variety of sites. Written opinions and recommendations are obtained from the Geological Survey of Alabama through the Alabama Water Improvement Commission, the State regulatory agency for water quality standards. Recommendations may include the desirability of having soil borings or other data furnished by local interests. These opinions frequently comment generally on such matters as drainage or specifically on the necessity for a structural control measure such as a clay liner. Almost all gravel and sand pits and quarries are rejected. It is estimated that less than fifty percent of Alabama's coal strip sites are useable as sanitary landfill sites.

Contrary to popular opinion, sites are difficult to find in Alabama due to the permeability of the soils in the Coastal Plain, the limestone terrane in central and northern counties, and the clays in the central and western counties usually identified as the Black Belt. The Gumbo soils of the Black Belt are particularly difficult. These soils are extremely hard when dry, impossible to work when wet, and exhibit large and irregular cracks when redried. In the northern counties, for instance around Huntsville, bedrock is shallow and encountered often. Bedrock in limestone terranes is hazardous because of the probability of solution channels that are difficult to trace to final destination. Waltz (1972) discussed similar problems related to thin soils in describing methods of geologic evaluation of pollution potential at mountain homesites. In the southeastern counties of Alabama centered about Houston and Geneva Counties, sand and accompanying shallow water tables can lead to problems. Although geologists would have preferred different soil characteristics in this area of Alabama, there are two sanitary landfills operating successfully without pollution.

The experience in Alabama is that geologic or hydrologic considerations do not always control the selection of a sanitary landfill site. Public reaction may decide the issue of a suitable site versus the availability of a site.

Alabama has made no piezometric studies of sanitary landfill sites. A few monitoring wells were installed in an area operated as a dump prior to its conversion as a sanitary landfill meeting minimum standards. Some contamination was evidenced but cleared up after proper operation as a landfill.

Through June 1974, Alabama's 67 counties had a total population of 3,444,000. The incorporated population was 2,048,000 and the unincorporated population was 1,396,000. Table 1 indicates several significant facts about the Solid Waste Management Program in Alabama. Of the 64 County-Regional System Landfills embracing 96 percent of the counties, only 12 percent of these landfills are substandard. Eighty-nine percent of the State's population, or 3,057,800, are served by adequate sanitary landfills. Only 3 percent of the State's population, or 94,300 people, are served by open dumps.

Figure 1 indicates the dramatic progress in population served by solid waste and disposal

Table 1. Alabama Solid Waste Management Status as of: 6/30/74
Counties: 67; State Pop.: 3,444,000; Incorporated Pop.: 2,048,000; Unincorporated Pop.: 1,396,000

Activities	*County/Regional Systems*		*Incorporated Cities and Towns*				*Unincorporated*		*State*	
	No.	*% Counties*	*No.*	*% Cities*	*Population*	*% Inc.*	*Population*	*% Uninc.*	*Population*	*% State*
Disposal:										
Sanitary Landfill	56	84	338	86	1,841,400	90	1,216,400	88	3,057,800	89
Substandard Landfill	8	12	35	9	180,600	9	111,300	7	291,900	8
Open Dump	3	4	19	5	26,000	1	68,300	5	94,300	3
Collection:										
House-to-House	38	57					937,100	67		
Container	19	28					305,300	22		
Combination(s)	1	2					19,400	1		
Total Adequate	58	87	386	98	2,046,300	99	1,261,800	90	3,308,100	96
None, or Not Organized	9	13	6	2	1,700	1	134,200	10	135,900	4

facilities since 1968. In 1968, 4.5 percent of the counties representing 17.9 percent of the total State population had total programs. In 1974, 87.0 percent of the counties representing 97.0 percent of the total State population had total programs. Figure 2 shows that since 1968, the unincorporated population percentage served by solid waste collection and disposal facilities has grown from 5.3 percent to 95.0 percent and that the incorporated population of the State so served has grown from 25.8 percent to 99.0 percent. The incorporated population reflects all cities and towns regardless of size. About 53 percent of Alabama's incorporated municipalities have populations of 1,000 or less.

The two greatest problems in the sanitary landfill program in Alabama are disposal of hazardous industrial wastes and training of operators. At the local level effective collection of fees is a major problem, although not directly related to protection of ground-water quality. Two industries manufacturing pesticides in Alabama operate their own approved landfill for disposal of their own hazardous wastes. One industry ships 12 barrels of hazardous wastes each week to Minnesota where proper incinerator disposal facilities are available; land disposal of these wastes probably would cause pollution of ground water. At the request of the Division of Solid Waste and Vector Control, the Geological Survey of Alabama restudied about 25 operating approved sanitary landfills for possible use as disposal sites for

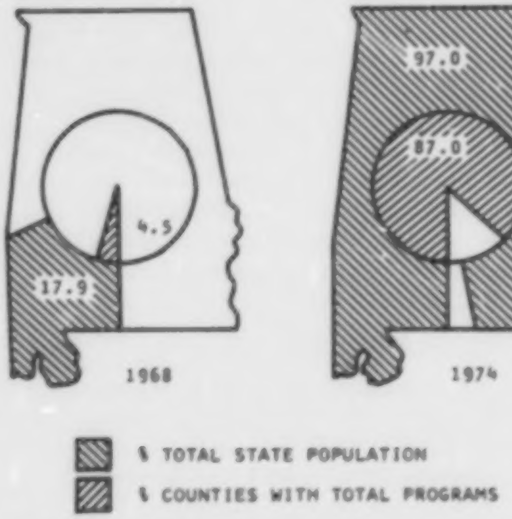

Fig. 1. Percent of Alabama population served and percent of counties with total collection and disposal programs.

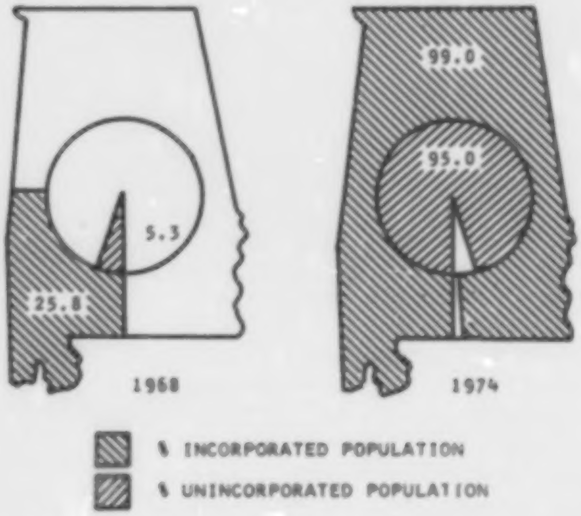

Fig. 2. Percent of incorporated and unincorporated population served by total programs in Alabama.

hazardous materials. Eight sites were designated as possibly suitable with final determination dependent on the results of detailed studies recommended by the Survey.

The Division of Solid Waste and Vector Control has requested authorization to add one professional who would work as a training specialist with operators of landfill sites. Following development of a training program, the Division may recommend that operators be certified.

CURRENT RESEARCH

Information about current research on ground-water pollution related to sanitary landfills was obtained by securing SSIE research information package LAO2H, which is intended to include sanitary landfills and sites and prevention of pollution of soils, surface and ground waters from landfill leachates. The package is one of many available from the Smithsonian Science Information Exchange; new listings of available research information packages are published in every issue of the SSIE Science Newsletter.

Ten research projects described in the information package are developing procedures for operation and management of sanitary landfills. Several of these projects include the development and operation of training programs for operators of landfills. J. M. Huie is conducting one of the more comprehensive studies at Purdue University, analyzing factors affecting the supply and demand of selected public services including evaluation of the economic feasibility of a regional solid waste collection and disposal system for southwestern Indiana. W. E. Hardy at Auburn University is emphasizing transportation economics in designing minimum cost solid waste collection and disposal systems, maintaining concern for protection of ground-water quality by considering only landfill sites that have been determined geologically suited for landfills. F. J. Forsberg is conducting a two-year demonstration project in Minnesota that should lead to development of legislation, ordinances and standards of city, county and regional systems and assist in improving solid waste management practices. Several of the operation and management studies are developing education programs to acquaint the public with the need for solid waste control to protect the quality of our resources. D. Massey at the University of Wisconsin is studying the reasons for and extent of opposition from private citizens in the north central States to location of sanitary landfills in rural residential areas as part of a study leading to recommendations for institutional arrangements needed for solid-waste management on an area-wide basis.

Thirty-two environmental geology studies are underway in areas ranging from Hawaii to the northeastern States. A few of these studies are concerned solely with determination of the degree of ground-water contamination from sanitary landfills. One is simply a baseline study of the geology and hydrology of a proposed landfill site. Most of these studies are more comprehensive and include development of criteria for operation of landfills in many kinds of sites—karst, abandoned gravel and mine pits, glacial drift floodplains, terraces, several soil types, coastal zones, and others—and in all of these studies the criteria for operation are intended to provide maximum protection for ground and surface waters and insure operations that meet the standards of a sanitary landfill. Several of the studies include development of field, electric analog or mathematical models to predict the movement of contaminants from sanitary landfills. A. A. Fungaroli and D. A. Brunner at Drexel University expect to include in their models potential remedial procedures for existing leaching landfills.

The Indianapolis Department of Public Works, regulating body for Marion County, has made as part of their reissue of landfill-operation permits, provision that all landfills be monitored by wells. This requirement likely will be widely adopted. J. R. Marie of the U.S. Geological Survey is conducting the monitoring program in Marion County. D. A. Rickert, with the U.S. Geological Survey in Reston, Virginia, has been determining the water quality parameters, frequency of analysis, methods of sampling, and types of sampling networks that are required to effectively monitor the hydrologic aspects of sanitary landfills.

Several specialized studies are underway that should result in tools or procedures to help solve field problems. These studies include the use of remote sensing techniques, the relationship between topographic position and contamination of water resources by landfills, the development of design criteria and operating techniques for landfill operation in high ground-water table areas, and geochemical studies forming the basis for formulation of chemical models for the evolution of ground-water chemistry as it responds to influxes of leachate.

Tools and materials are being developed and evaluated in a few research projects. The California Department of Water Resources has been developing a well sampler for collecting dissolved gases and other components in ground water. J. L. Melnick has been studying the use of a portable virus concentrator for determining the distribution and survival of enteric viruses in leachates from municipal sanitary landfills. R. C. Jones with Ohio's Crawford County Board of Commissioners has been evaluating the economic and technical feasibility of using a commercially available shredder to partially degrade or compost refuse. D. D. Blue and T. A. Sullivan of the U.S. Bureau of Mines are determining the applicability of sulfur for constructing impervious ground cover bases or liners for sanitary landfills. H. E. Haxo with Woodward, Lundgren and Associates has been evaluating the effective life of 12 different liner materials when exposed to leachate from municipal landfills.

Research on leachate includes development of procedures for collection and recycle to the landfill, collection and treatment as an effluent, attenuation by earth materials, and transpiration drying of the landfill.

As regulations have tightened on protection of the quality of surface water and air, more waste is being disposed onto the surface or into our land, and research is underway on some of these practices. D. L. Reddell at Texas A and M is studying the machinery, tillage techniques and landfill disposal systems necessary for applying large rates of animal manure. W. Kam of the U.S. Geological Survey and J. D. Menzies and W. D. Kemper of the U.S. Department of Agriculture in separate studies have been developing ways to protect ground-water quality where sludge from a municipal sewage treatment plant is placed in the ground. O. B. Andersland at Michigan State University is investigating methods for efficient and safe disposal of dewatered high ash content pulp and paper-mill sludges in landfills. Only three research projects on disposal of pesticide waste and pesticide containers were included in the information package. No other research was reported that gave principal concern to disposal to landfills of hazardous industrial wastes; therefore, this may be the most critical research need.

State Geological Surveys in Alabama and North Dakota, among others, are producing reports for the educated non-geologist on environmental geology and the special problems related to operation of sanitary landfills. These reports emphasize the potential for pollution of surface water and ground water and procedures necessary to provide adequate protection.

You should be aware of the continuing program in the U.S. Environmental Protection Agency to compile and publish a bibliography on the influence of solid waste management practices on the quality of surface water and ground water. EPA uses its Solid Waste Information Retrieval System and other sources to compile the bibliography.

REFERENCES

Waltz, James P. 1972. Methods of geologic evaluation of pollution potential at mountain homesites. Ground Water. v. 10, no. 1, pp. 42-49.

APPENDIX A

ALABAMA SOLID WASTE LAND DISPOSAL SITE EVALUATION

Location of Site: ____________________
Area Serviced: ____________________
Responsibility: ____________________
Rater: ______________ Date: __________
Site Objective: ________Sanitary Landfill________Landfill
________Trash Dump______Garbage Dump
Rating Points: __________Acceptable: ______Yes______No

Note: To be acceptable in meeting minimum State standards, *none* of the following may be checked:

______ Burning of refuse is permitted on site.
______ Refuse (contains garbage) is *not* compacted and covered daily as used.
______ Water pollution is a recognized problem.
______ *Hazardous wastes *are not* properly managed.

Comments:

LAND DISPOSAL SITE

1. Usage	
(a) All wastes manageable in sanitary landfill	25
(b) Bulky rubbish stored at sanitary landfill	20
(c) Garbage & municipal refuse only—sanitary landfill	15
(d) Rubbish only (landfill or open dump)	20
(e) All wastes (landfill or open dump)	10
2. Burning	
(a) Not practiced	25
(b) Obvious possibility of fire	10
(c) Deliberately practiced or permitted	0

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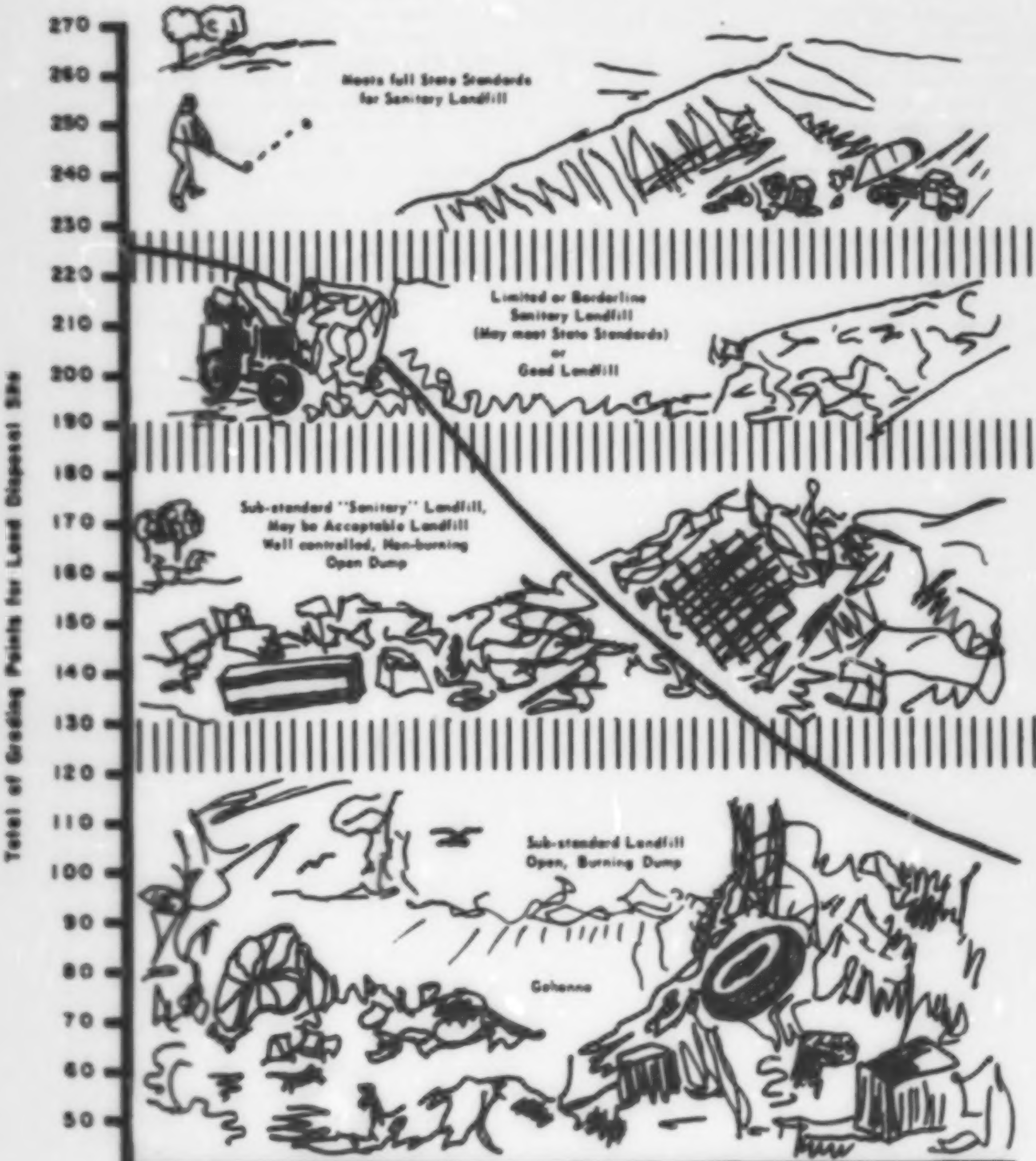
*Hazardous wastes are considered to be those in excess of reasonable household or business wastes, as quantities of pesticides or containers from a large pesticide user, toxic wastes from a manufacturer or other generator, or similar wastes that could be a serious hazard in a normal disposal site.

RATING CHART USED FOR ENFORCEMENT
SOLID WASTE LAND DISPOSAL SITE, ALABAMA STATE DEPT. OF PUBLIC HEALTH



Division of Solid Waste & Vector Control
1972

3. Water Pollution	
(a) No recognized problem—sanitary landfill	25
(b) No recognized problem—landfill	20
(c) Very occasional ground water or leaching—sanitary landfill	15
(d) Very occasional ground water or leaching—landfill	10
(e) Any serious problem	0
4. Equipment	
(a) Adequate for type of operation	20
(b) Limited for type of operation	10
(c) None or totally inadequate	0
5. Equipment Facilities	
(a) Satisfactory shelter & servicing	10
(b) Open on-site servicing	5
(c) Off-site servicing	2
6. Personnel	
(a) Sufficient to operate equipment and control site	20
(b) Limited in number or work quality	10
(c) None or ineffective	0
7. Personnel Facilities	
(a) Satisfactory (includes toilet facilities & telephone	10
(b) Limited (not convenient or complete)	5
(c) Shelter only	2
(d) None	0
8. Access Road	
(a) All weather road to site	15
(b) Adequate road	7
(c) Unsatisfactory	0
9. Cover Quality	
(a) Good quality, on-site	15
(b) Good quality, off-site	10
(c) Low quality	5
10. Cover Practices	
(a) As required for type of operation	15
(b) Cover less than or more than needed	7
(c) Cover lacking or totally inadequate	0
11. Compaction Practices	
(a) As required for type of operation	15
(b) Poor compaction techniques	7
(c) Compaction totally inadequate	0
12. Operating Face	
(a) Controlled and confined (operating on slope for SLF)	10
(b) Too thick for proper compaction	7
(c) Too thin and scattered	5
(d) Out of control	0
13. Housekeeping	
(a) Litter controlled	10
(b) Limited control	5
(c) Uncontrolled	0
(d) Scavenging permitted	(neg.) −10
14. Fire Control	
(a) Adequate water or firebreak	10
(b) Control needed or burning permitted on site	0
15. Vector Control	
(a) Regularly practiced or not needed	6
(b) Sporadic control	3
(c) Control needed	0
16. Site Plan	
(a) Planned for specific ultimate use	6
(b) General land improvement	3
(c) No plan for future use or plan not followed	0
17. Site Reliability	
(a) Provision for wet weather operation	5
(b) Provision needed	0
18. Public Access (Users)	
(a) Controlled at entrance or container	5
(b) Allowed on site, directed	3
(c) Uncontrolled	0
19. Site Security	
(a) Access denied by fence or other means, and gate locked when site unattended	8
(b) Site secured by fence or natural boundaries, but entrance uncontrolled	4
(c) No site security	0
20. Records	
(a) Weighing or good volumetric check	5
(b) Vehicle count, estimated quantity	3
(c) No records	0
21. Special Provisions	
(a) Separate trench for immediate burial of large dead animals, highly putrescibles (eggs, etc.) or similar problem wastes	8
(b) No consideration for above or no problem	0
(c) No consideration for abnormal quantities of hazardous wastes, if received	(neg.) −20
	(neg.) −40
22. Site Progress	
(a) Adequate final cover and contour	5
(b) Finish needs improvement	0
(c) Obvious problem with erosion and/or leachate	(neg.) − 5
	(neg.) −10
	(neg.) −20

Alabama State Department of Public Health
Environmental Health Administration
Division of Solid Waste & Vector Control
1972

ALABAMA RURAL COUNTY-WIDE SOLID WASTE MANAGEMENT EVALUATION

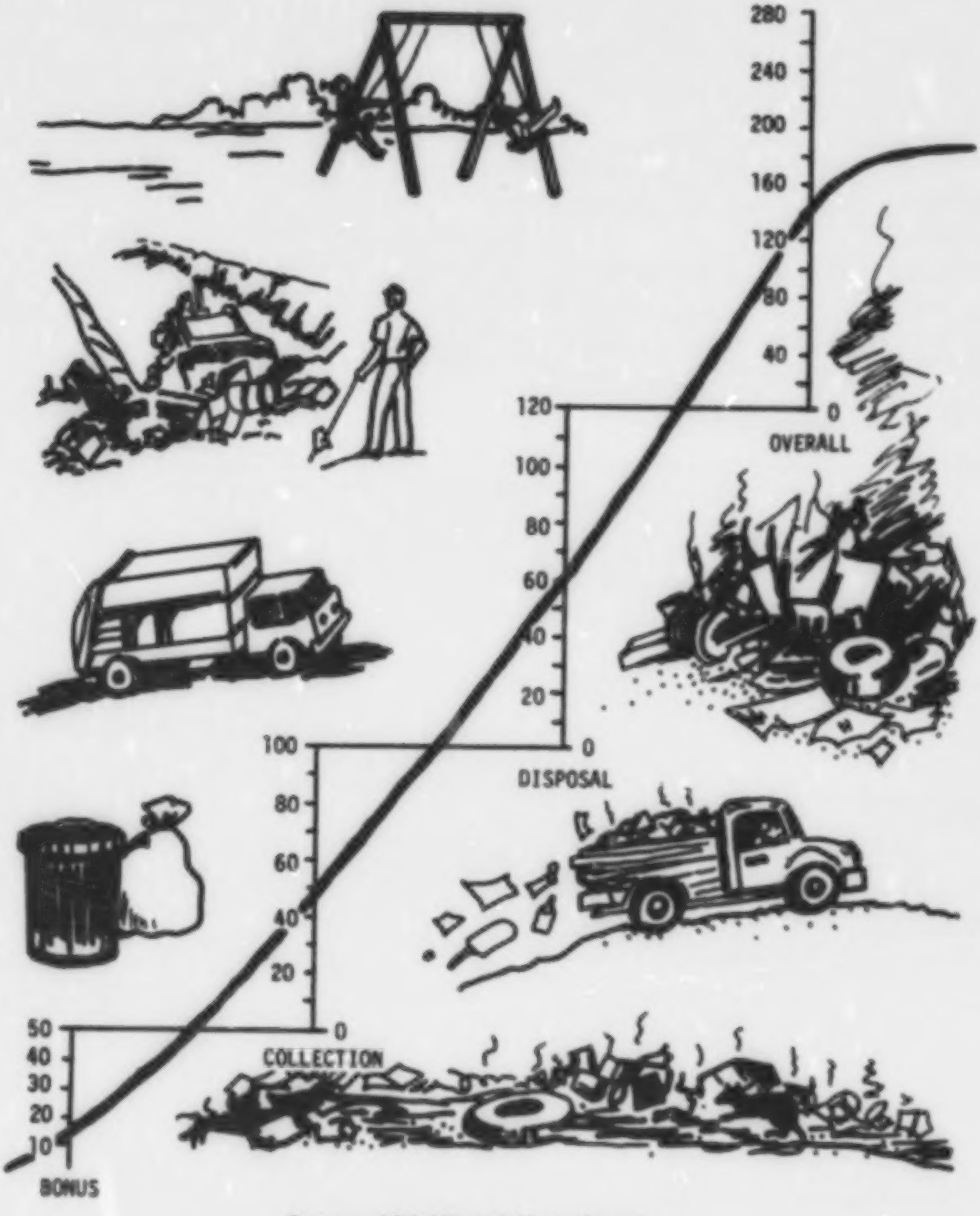
County ____________ Disposal points ____________
Rated by ____________ Collection points ____________
Date ____________ Bonus points ____________
Over-all rating ________ Acceptable ________ Yes ________ No

House-to-house ________ County operated ________
Container ________ Franchised ________
Combination ________ Other ________

Comments ____________________________________
____
____
____

Alabama Department of Public Health
Environmental Health Administration
Division of Solid Waste & Vector Control
August, 1972

RATING CHART USED FOR GENERAL INFORMATION
SOLID WASTE MANAGEMENT PROGRAMS
COUNTY-WIDE
ALABAMA



Division of Solid Waste & Vector Control
1972

COUNTY-WIDE COLLECTION SYSTEMS

		Point Value Range	*Rated Points*
Either	A. County operated "mailbox" system:		
	1. Serves rural areas –		
	Above 60% of households	75 to 100	
	40% to 60% of households	60 to 75	
	Less than 40% of households	40 to 60	
Or	B. County franchised "mailbox" system:		
	1. Serves rural areas –		
	Above 60% of households	65 to 90	
	40% to 60% of households	50 to 65	
	Less than 40% of households	30 to 50	
Or	C. Bulk container system:		
	1. Serves rural areas	50 to 75	
Or	D. Combination "mailbox" and container system:		
	1. Serves rural areas	80 to 100	
Or	E. No organized system:		
	1. Nonfranchised rural collection serves:		
	More than 50% of households	25 to 40	
	25% to 50% of households	15 to 25	
	0% to 25% of households	0 to 15	
Additional points:			
	1. System serves one or more municipalities (see note)	10	
	2. One or more municipalities have *no* organized collection	−10	

NOTE: No credit is given for municipal collection unless conducted by county or county-franchised system. Negative credit is given for small municipalities (generally under 1,000 population) having *no* organized collection.

COUNTY-WIDE DISPOSAL SITES

	Point Value Range		*Rated Points*
	Meets minimum standards	*Substandard*	
A. Site(s) serve a rural system –	20 to 40	20 to 40	
And 1. Operated as sanitary landfill and controlled by county	40 to 60	20 to 30	
Or 2. Controlled by municipality	30 to 50	10 to 20	
Or 3. Operated through county franchise	20 to 40	5 to 10	
B. *Site(s) operated by municipality where no rural collection system exists	20 to 40	10 to 20	
Additional points for rural disposal systems:			
For one or more *additional* sites			
1. 1. In counties below 30,000 population	15	7	
2. In counties 30,000 to 70,000 population	10	5	
3. In counties above 70,000 population	5	2	
4. When any county has multiple sites, and majority are substandard	–	−10 to −20	
*Section B is only considered when no disposal site is designated by a county-municipal agreement for the disposal of rural wastes.			
Bonus Points			
1. County has an independent solid waste authority	15		
2. County has adopted rules and regulations	10		
3. County has appointed Solid Waste Supervisor – Full-time	10		
Part-time	5		
4. County has concentrated effort on unauthorized dump cleanup	0 to 15		

DISCUSSION

The following questions were answered by the authors after delivering the talk entitled "Will Current Research Answer Today's Problems at the Sanitary Landfill?"

Q. by Timothy J. Bergin. *Are there any special regulations for disposing of septic tank sludges and have you noticed any specific leachate problems attributable to these sludges?*
A. We are not aware of such regulations nor of any practice of disposing of septic tank sludges (from "honey trucks") in sanitary landfills.

Q. by Thomas N. Canfield. *Could you expand on the degree of review of site geology at a landfill site in Alabama? Please explain your statement that technical evaluations of sites are sometimes overruled.*
A. The Geological Survey of Alabama study of a proposed sanitary landfill site includes determination of other land use within the vicinity, uses and potential uses of ground water and surface water, probable direction of movement of ground water, details of construction used for wells in the vicinity, position of the water table (minimum 30 feet from base of landfill to water table if possible), controls necessary to avoid surface-water flow across the site, depth to bedrock (boring to 30 feet or top of bedrock), and the amount of clay in the regolith. The Survey prefers high percentages of clay; however, the regulatory agency must be sympathetic to problems of site operators regarding workability of the regolith. The Survey does not run percolation tests nor does it make detailed study by boring; its report may include recommendation for more detailed study. As stated in the paper, public reaction may decide the issue of a suitable site versus the availability of a site. Determination of other land use within the vicinity is an important part of any site study. Failure to consider it invites strong public reaction.

Q. by J. Koutsand. *What methods should be used to dispose of pathological wastes?*
A. Incineration with proper equipment at the proper place; for example, such wastes from a hospital should be incinerated at the hospital to avoid risks involved in transporting wastes to an incinerator at another location.

Q. by Greg Stockert. *In Alabama how many landfills are being monitored by wells? What is the procedure for treating leachate from sanitary landfills to render them nonpolluting?*
A. Only 6 or 7 landfills are monitored by wells in Alabama at this time. Treatment of leachate has been described in recent issues of the *Journal Water Pollution Control Federation.* The current volume 46 (1974) includes an article entitled "Treatability of Leachate from Sanitary Landfills by Biological Methods," by W. C. Boyle and R. K. Ham and a follow-up article by S. Ho, Boyle and Ham entitled "Chemical Treatment of Leachates from Sanitary Landfills."

Q. by John O. Osgood. *We have learned in Pennsylvania that natural renovation is an excellent theoretical tool for sanitary landfill development; however, practically, it has been a failure. We are headed in our program to environmental isolation with collection and treatment. Natural renovation will not be permitted. What is your feeling on this approach?*
A. We are not familiar with the details of your work in Pennsylvania on "natural renovation" versus "environmental isolation with collection and treatment." Assuming that others are unfamiliar, we recommend that the THIRD National Ground Water Quality Symposium provide time for a presentation of your findings.

Leachate Plumes in a Highly Permeable Aquifer[a]

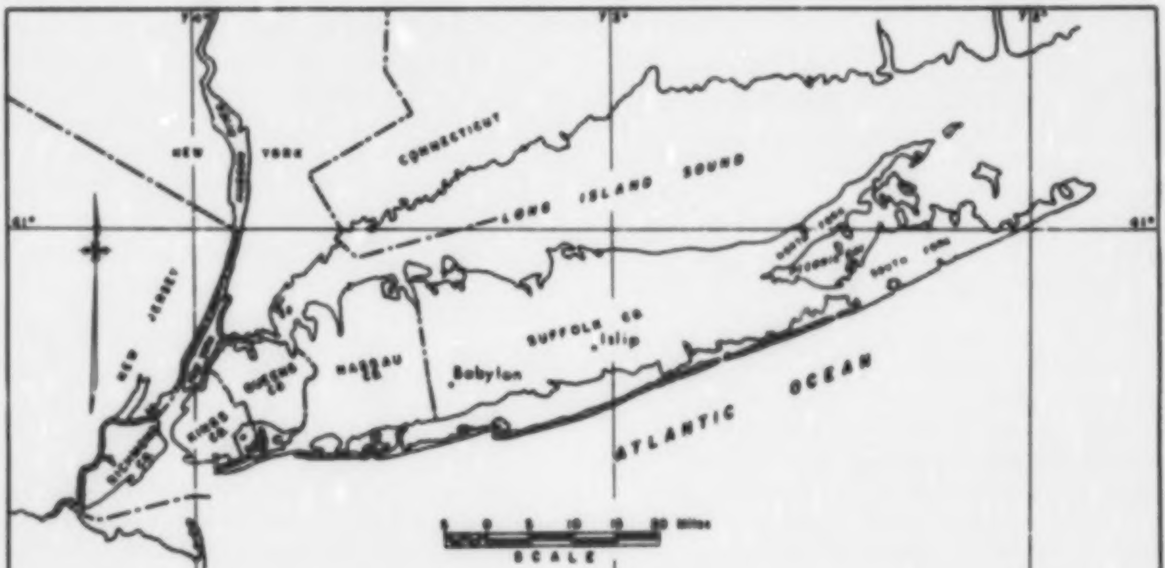
by Grant E. Kimmel and Olin C. Braids[b]

ABSTRACT

Two landfills, 27 and 41 years old, were studied and found to have plumes of leachate-contaminated ground water extending 10,600 and 5,000 ft (3,200 and 1,500 m), respectively, from the site of deposition in the upper glacial aquifer on Long Island, New York. The plumes sink to the bottom of the aquifer, which is 70 ft (21 m) below the water table at the 27-year old site and 170 ft (52 m) below at the 41-year old site. The aquifer has a hydraulic conductivity of 270 ft per day (80 m per day).

Amounts of Na^+, HCO_3^-, and Cl^- and occasionally amounts of Ca^{++}, are greater in plume water than in ambient ground water. Percentage of $SO_4^=$ increases away from the landfills. Nitrogen in plume water is mainly in the form of NH_4^+. The pH of plume water decreases from about 7 near the landfill to a native water value of about 5 along the perimeter of the plume. Heavy metals other than iron, manganese, and zinc were not found in concentrations greater than several tens of micrograms per litre away from the landfill. Selenium concentration in plume water is occasionally greater than 10 µg/l. The extent of ground-water contamination caused by the landfills suggests that size and growth rate of a landfill are more significant than age. Depending on geologic conditions, ground-water contamination near a landfill might be avoided on Long Island by lining the pit and collecting the leachate.

A study of landfills in Suffolk County, Long Island, was begun in 1972 in cooperation with the



*Location of landfills in towns of Babylon and Islip

Fig. 1. Location of Babylon and Islip landfills in Suffolk County, Long Island, New York.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974. Work done in cooperation with the Suffolk County Department of Environmental Control.

[b] Hydrologists, U.S. Geological Survey, Mineola, New York 11501.

Suffolk County Department of Environmental Control to determine the effect of landfills on ground-water conditions there. Two landfills, with widely differing ages and rates of refuse accumulation but with similar geohydrology, were selected for the study. One was in the Town of Babylon and the other in the Town of Islip. Since the beginning of the study, 3 major sets of water-quality samples have been collected from 170 points throughout the affected region of the aquifer. This report is a summary of the data from 2 sets of the water analyses.

The Town of Babylon landfill (Figure 1) is the main refuse disposal facility for a population of about 200,000. The landfill covers 25 acres (10 ha), contains 2.3 million yds^3 (1.7 million m^3) of refuse, and is 27 years old. The Town of Islip landfill (Figure 1), at Sayville, is 1 of 3 landfills for a population of 290,000. This landfill covers 17 (7 ha) acres, contains 0.8 million yd^3 (0.6 million m^3) of refuse, and is 41 years old. Both landfills have incinerators and have received scavenger waste, though the Islip landfill no longer does.

The landfills are on an outwash plain that is underlain mainly by coarse sand and a few streaks of gravelly and fine sand. This deposit is known as the upper glacial aquifer on Long Island (Cohen and others, 1968). At the Babylon landfill, the bottom of the upper glacial aquifer is 70 ft (21 m) below the water table, which is 15 ft (4.6 m) below the land surface, and is underlain by the Gardiners Clay (Jensen and Soren, 1971), a single 12-ft (4-m) thick clay layer. At Islip, beds of fine sand and silt near the base of the aquifer effectively reduce the hydraulic conductivity and form a hydrologic boundary about 170 ft (52 m) below the water table. The landfills bottom at the water table (about 20 ft or 6 m below land surface at the Islip site). Plumes from the landfills flow vertically through the full thickness of the aquifer and downgradient, as shown in Figures 2, 3, and 4.

The hydraulic conductivity of the upper glacial aquifer is estimated to be 2,000 gal/day^{-1}/ft^{-2}, or 270 ft/day^{-1} (80 m/day^{-1}) (McClymonds and Franke, 1972). At the prevailing hydraulic gradient at these sites, ground water moves at a velocity of 2 ft/day^{-1} (0.65 m/day^{-1}) toward saltwater bays that are 4 miles (6.4 km) south of the Babylon site and 3 miles (4.8 km) south of the Islip site.

The plume at Babylon occupies the full thickness of the aquifer (Figures 2 and 3) and, for most of its length, contains a higher concentration of leachate than the one at Islip. At Babylon, ambient water contaminated by septic-tank waste has a specific conductance of as much as 400 μmhos cm^{-1}. At this conductance, the Babylon plume can be traced for 10,600 ft (3,200 m) from the original site of refuse deposition.

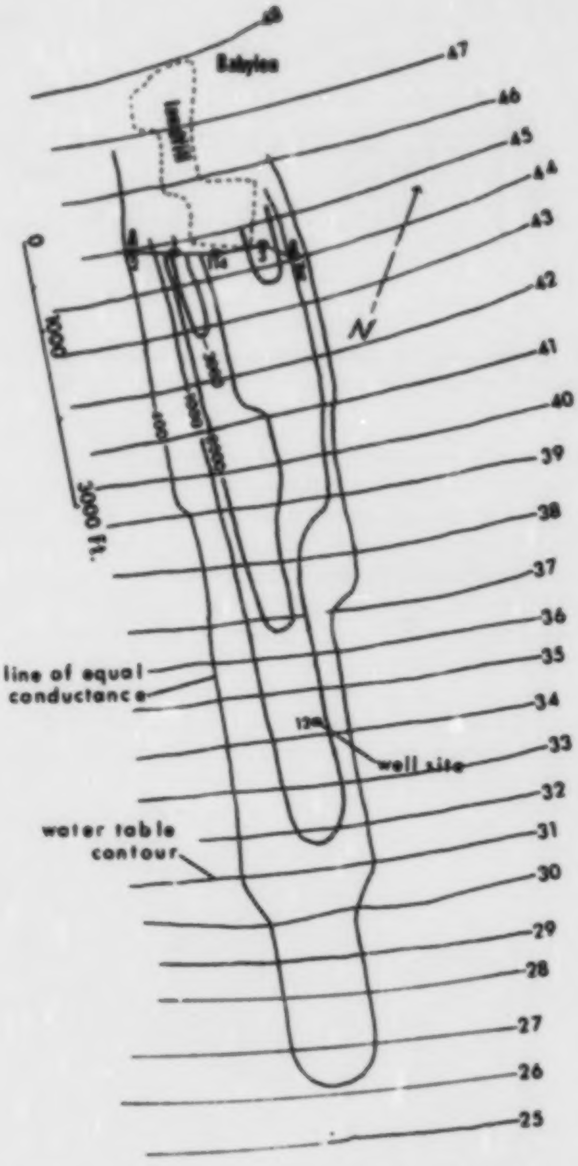

Fig. 2. Lines of equal specific conductance, in micromhos per centimeter at 25 degrees C, and of equal potentiometric head on the water table, in feet above mean sea level, for ground water downgradient from the Town of Babylon landfill. The cross section A–A' is shown in Figure 3.

The plume at Islip (Figure 4) flows near the bottom of the aquifer along a hydrologic boundary for 5,000 ft (1,500 m) from the original site of deposition. Because thickness of the aquifer at the Islip site is greater than that at Babylon, the top of

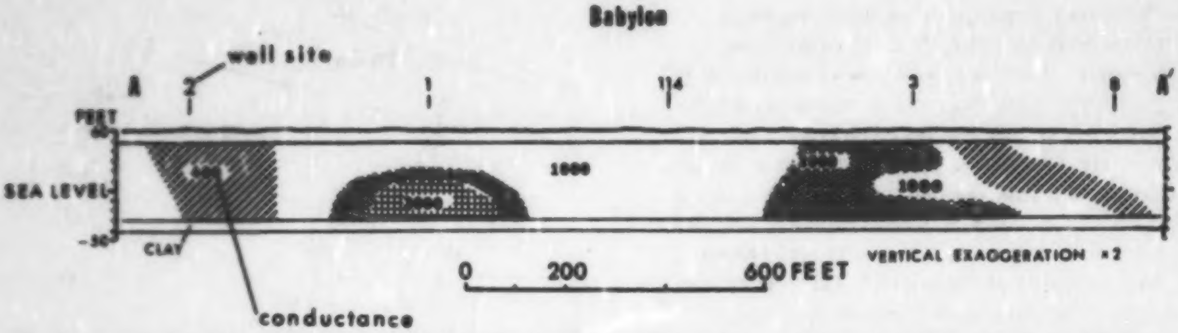
Babylon
well site
A
2
1
114
3
8
A'
FEET
60
SEA LEVEL
-30
CLAY
1000
1000
VERTICAL EXAGGERATION ×2
0
200
600 FEET
conductance

Fig. 3. Cross section of upper glacial aquifer at Babylon landfill showing specific conductance in micromhos per centimeter in region of contamination. Location of section shown on Figure 2.

the plume slopes downward and occupies a position about 60 ft (18 m) below the water table about 3,000 ft (900 m) south of the landfill. At Islip, ambient water near the bottom of the aquifer is little contaminated by other sources and has a specific conductance less than 100 μmhos cm^{-1}. The plume flowing near the bottom of the aquifer is easily identified by the contrast in conductance between plume water and ambient ground water.

Sodium chloride and sodium bicarbonate types of water are present in both plumes. Stiff diagrams of the water quality at various depths at site 12 at Babylon are shown in Figure 5. Sodium is the dominant cation. Chloride is dominant at 19, 40, and 78-foot (5.8, 12.2 and 23.8 m) depths; bicarbonate is dominant at the 62-ft (18.9 m) depth, and the 2 anions are almost equal in concentration at the 48-ft (14.6 m) depth. Chloride is the dominant anion at some localities near the Babylon site, whereas bicarbonate is dominant at other localities.

Chemical quality of ground water in the plume at Islip at sites 23 and 8 (Figure 4) is shown in

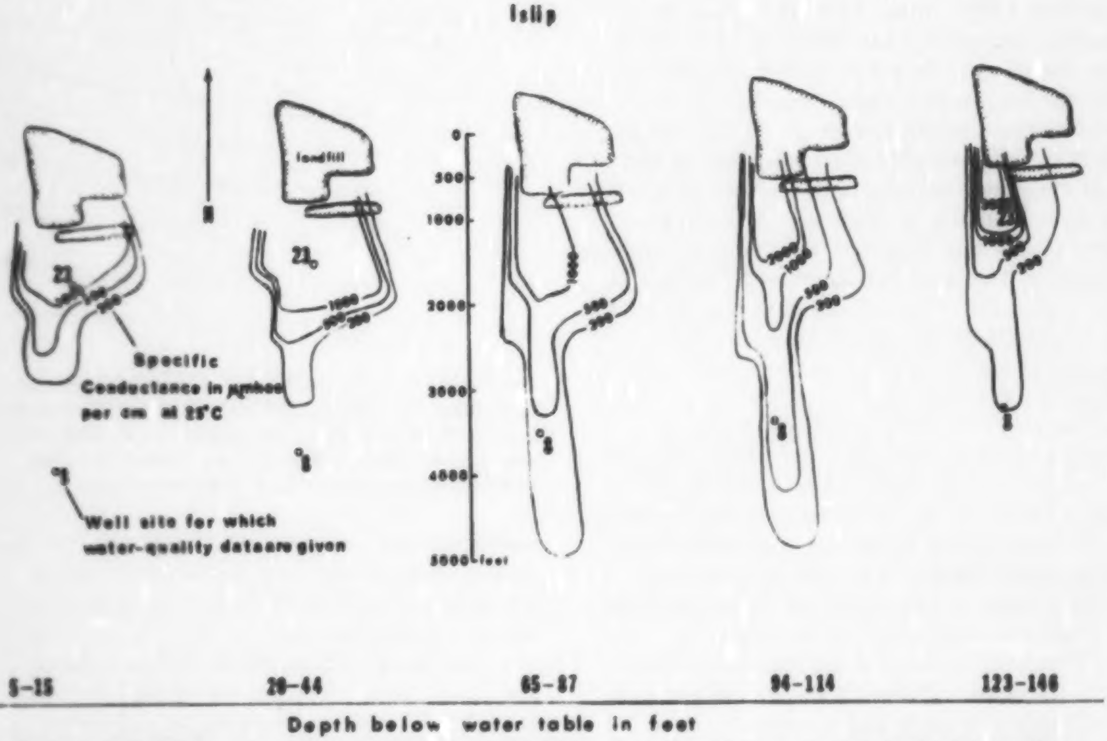
Islip
N
landfill
23
23
8
8
8
8
0
500
1000
2000
3000
4000
5000 feet
1000
500
200
Specific
Conductance in µmhos
per cm at 25°C
Well site for which
water-quality data are given
5-15
20-44
65-87
94-114
123-148
Depth below water table in feet

Fig. 4. Specific conductance in micromhos per centimeter at 25 degrees C of ground water at various depths downgradient from the Town of Islip landfill.

Figure 6. Site 23 is about 1,000 ft (300 m) from the landfill or about one-fifth the length of the plume. These analyses show that leachate enrichment is greatest near the bottom of the aquifer. Bicarbonate is the dominant anion in water at a depth of 123 ft (37.5 m). Water from this depth had about the highest dissolved-solids concentration (1,550 mg/l) of any water samples at the Islip site. At site 8, 2,200 ft (670 m) downgradient from site 23, the maximum dissolved-solids concentration was 0.3 of that at site 23. At site 8, the plume lies between depths of 60 and 140 ft (18 to 43 m) below the water table. The maximum leachate concentration is near the bottom of the plume. Both plumes share this characteristic, probably because of the difference in hydraulic conductivity between leachate and ambient water at the heads of the plumes.

Most of the nitrogen in the plumes is in the reduced form, NH_4^+, whose concentration ranges from 10 mg/l near the distal end of the plume to 90 mg/l near the landfill. In comparison, NO_3^-, the oxidized form, is generally less than 1 mg/l.

As a percentage of total ions, $SO_4^=$ increases downgradient. In some places near the distal end of the plumes, it is the dominant anion. In the plumes near the landfills, sulfate concentration was less than 5 mg/l in water from many wells. As there was no indication of H_2S in the water, sulfur must be nearly absent in parts of the plume.

Of the heavy metals, arsenic, cadmium, chromium, cobalt, copper, nickel, lead, and zinc, only zinc was consistently found in the plumes in concentrations greater than several tens of micrograms per litre. Zinc was found in concentrations as much as several hundred micrograms per litre near and downgradient from the landfills. Concentrations of iron and manganese were as much as 400 and 190 mg/l, respectively, in water from wells near the landfills but were much less farther away from the landfills.

The U.S. Public Health Service Drinking Water Standard (1962) of 10 μg/l for selenium is exceeded at many sites within the plume and at some locations outside the plume as well. Concentrations of selenium were as much as 40 μg/l in places up to the distal end of the plume at Babylon but were less than 10 μg/l in the plume at Islip.

The pH in most of the leachate-enriched ground water ranges from about 7 near the landfills to about 5 near the perimeter of the plume, where the pH approaches that of ambient water, 4 to 6.

Higher concentrations of Na^+, Ca^{++}, HCO_3^-, and Cl^- in plume water than in ambient water distinguish plume water. Plume water is generally

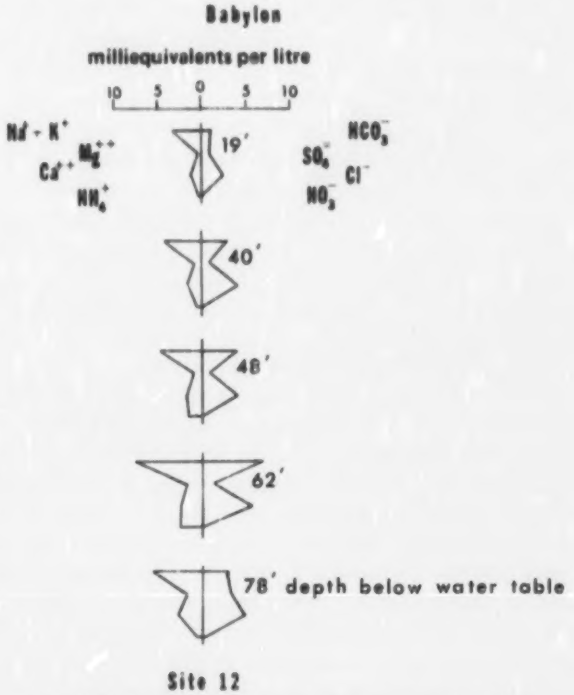

Fig. 5. Stiff diagrams showing ground-water quality in the Babylon plume.

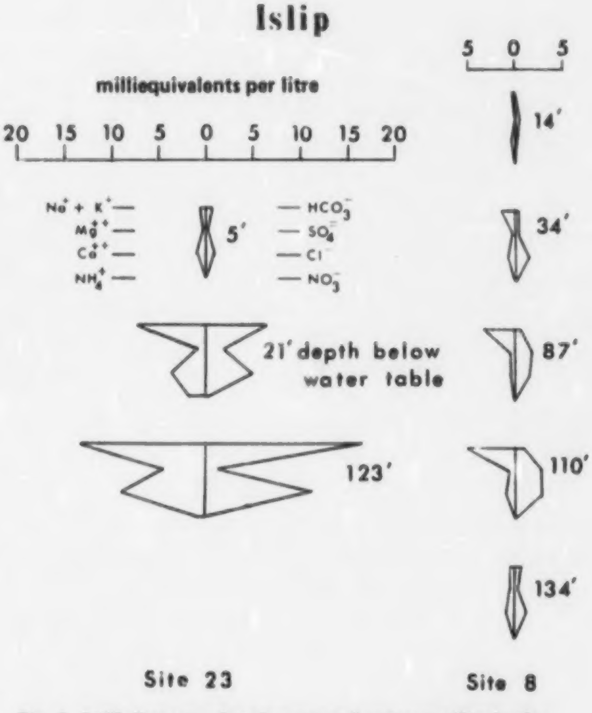

Fig. 6. Stiff diagrams showing ground-water quality in the Islip plume.

of a reduced chemical character, but near the edge of the plume the percentages of oxidized species, $SO_4^=$, and NO_3^-, increase.

The plumes did not spread significantly beyond the width of the landfills. Dispersion theory suggests at least some lateral spread. Perlmutter, Lieber, and Frauenthal (1963) found some lateral spread in a chromate-rich plume in a similar geological and hydrological situation on Long Island. Longitudinal dispersion is difficult to evaluate because of the highly variable strength of the leachate.

Length of both plumes is less than that calculated on the basis of average ground-water velocity and age of landfill. Actual length is 0.7 of the calculated length at Babylon and 0.4 of that at Islip. And though the Islip landfill is 15 years older than the Babylon landfill, the Islip plume is only about half as long as the one at Babylon. Volume of water in the Islip plume is about half that in the Babylon plume and, similarly, the amount of refuse at Islip is a little less than half that at Babylon. Apparently length and volume of the plume may be more closely related to the amount of refuse than to the age of the landfill.

Unless special precautions are taken, quantity of leachate-contaminated ground water produced by landfills on Long Island can be expected to increase as the amount of refuse in the landfill increases. The plumes described in this report seem to be free of highly injurious substances, although pumpage was reduced in one public supply well that tapped the Babylon plume because of increasing chloride concentrations. Wells several thousands of feet from the landfill are rarely affected by the plumes to an extent noticeable to the users.

In conclusion, lining the landfill and collecting the leachate to eliminate a potentially dangerous source of contamination may be worth the added cost. Volume of leachate produced in landfills already in operation could be reduced by increasing surface runoff from the landfill. In the future, in highly populated areas such as Long Island, landfills may not be used as extensively as in the past, and refuse may be recycled. The economics of recycling may be favorable even at this time (Albert, Alter, and Bernheisel, 1974).

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DISCUSSION

The following questions were answered by Grant Kimmel after delivering his talk entitled "Leachate Plumes in a Highly Permeable Aquifer."

Q. by R. G. Kazmann. *Are the conductivities measured at a single elevation or is it some sort of average over the entire 70 feet of aquifer? Reference is to the slides showing contours.*

A. The conductivities shown on the illustrations were measured within a short time interval at a horizon intermediate in depth for drawing of the Babylon plume and at several depths for the Islip plume. The Islip plume changes significantly with depth, but the Babylon plume has virtually the same shape a few tens of feet below the water table. The measurements were made from a group of wells set at various depths at one site.

Q. by Paul Plummer. *Is nearly all of the material in the landfill incinerator residue or have municipal or industrial wastes gone into the piles?*

A. The landfills consist of garbage, industrial waste which appears to be mostly odds and ends, bits of plastic and metal strips from fabricating industries, construction refuse, and incinerator ash. I have no measure of the proportion of each.

Q. by Donald D. Runnells. *You mention arsenic, boron and selenium in your abstract. What concentration have you seen for these components in the leachate?*
A. The maximum concentrations in the plumes, in μg/l, are: As-7, B-2000, Se-42.

Q. by D. Craig Shaw. *Did you look for organics?*
A. We analyzed some water samples for total organic and inorganic carbon. Organic carbon concentration generally increases with dissolved solids concentration, but the relationship is not proportional. The highest found was 2250 mg/l organic carbon in water from a well near the Babylon landfill, but this was exceptional as most analyses showed less than 20 mg/l.

Q. by Lynn Gelhar. *What was the density difference between the leachate and the native waters? What is the porosity of the aquifer?*
A. The density difference between leachate and native water could not be measured directly. Estimates of leachate density based on salt solutions with dissolved solids concentrations similar to that of leachate (5000-40,000 mg/l) indicate that there may be very little change (less than several parts in a thousand) in density as the solute content increases to 40,000 mg/l and the temperature increases to 40 degrees C. Also, the density of a salt solution ($NaHCO_3$) is *less* than native water by about 1 part in a hundred, at a concentration of 20,000 mg/l at 40 degrees C.

The porosity in the upper glacial aquifer is about 30 percent, but for calculations of velocity, we used 25 percent as the effective porosity.

Q. by Robert Palmquist. *What kind of control do you have? Number, location, depth of monitoring wells.*
A. We have wells dispersed throughout and beyond the region occupied by the plumes. There are about 70 wells at 30 sites at Islip and about 100 wells at 40 sites at Babylon. The vertical and horizontal control at Babylon is good because of the thinness of the aquifer there. At Islip the control is not as good, though good enough to identify the extent of leachate enrichment.

Q. by Ken Childs. *Did your leachate move in a mass or as individual constituents? How did variabilities in the regolith (such as texture and fabric adsorption) affect the shape and extent of leachate migration?*
A. Contrary to what you seem to have found, any given ion that is high in concentration at the head of the plumes can be used to trace the plume through the downgradient course; however, the conservation ion Cl^- is best. Dispersion of the plumes is controlled, in part, by the texture of the sediments. Dispersion is probably less than noted in other studies because of the coarseness of the grain size in this aquifer. The aquifer may also be anisotropic with a principal hydraulic conductivity in the direction of flow.

There is considerable adsorptive capacity in the aquifer because of iron oxide coating on the sand grains which make up the aquifer, but this coating has been stripped off in regions where the plume is strongly reducing in chemical character.

Q. by John Wilson. *(1) Why do you suppose there was no lateral dispersion reflected in your measurements? (2) Why is the plume shorter in longitudinal extent than one might guess it to be?*
A. The only reasons I have for lack of lateral dispersion is that the coefficient of lateral dispersion is a great deal smaller than the coefficient of longitudinal dispersion and consequently we just can't observe any effects and also there may be anisotropy in the aquifer as explained in the previous question. (2) Possibly our estimate of ground-water velocity is inaccurate.

Q. by Gary Small. *What amount of nitrification or denitrification took place at the air-water interface below the landfill itself?*
A. The water table intercepts the bottom of the landfill, thus leachate does not travel through a zone of aeration before entering the aquifer. Conditions inside the refuse piles are highly reducing, a condition which persists in the leachate and in leachate-enriched ground water beneath the refuse. Ammonium concentration is very high and nitrate very low. Denitrification probably does take place to a degree, but is limited by the small amount of nitrate present or produced in the refuse.

Transpiration Drying of Sanitary Landfills[a]

by Fred J. Molz, S. R. Van Fleet, and V. D. Browning[b]

ABSTRACT

Experiments are described which test the feasibility of diminishing the leachate production of sanitary landfills by using the roots of transpiring plants to dry the refuse and surrounding soil. Full-scale models of landfill cores were constructed and filled with typical municipal refuse in the early spring of 1973. Selected plant species such as slash pine, thorny elaeagnus, bristly locust, black locust, and two grasses were used to vegetate two landfill models, while a third was denied vegetation and used as a control. Intermediate term results have been positive from several viewpoints. The various species of selected plants have thrived, even though gas sampling indicated that the lower two-thirds of the landfill models quickly became anaerobic. Roots proliferated rapidly through the top 2½ feet (76.2 cm.) of cover soil and first refuse layer. Following December 1973, all three lysimeters began producing leachate. However, the volume of leachate produced differed considerably depending on whether the particular lysimeter was vegetated or fallow. To date, the unvegetated control has produced 17.53 inches (44.53 cm.) while the two vegetated models have produced 8.59 inches (21.82 cm.) and 2.49 inches (6.32 cm.) respectively. The lysimeter producing the minimum leachate volume was vegetated with pine and thorny elaeagnus. The unvegetated bin produced the most dilute leachate. If one uses the chemical oxygen demand, the total Kjeldahl nitrogen, and the total solids as indices representative of the potency of leachate, then the leachate from the lysimeter containing pine and thorny elaeagnus was 1.97 times more concentrated than that from the fallow lysimeter. Thus one realizes a net improvement factor of 3.57 due to the presence of plants.

INTRODUCTION

A sanitary landfill, properly designed and operated, is an economical method for disposing of solid wastes. A major drawback, however, is that water seeping through the refuse becomes grossly polluted and, in a poorly designed landfill, may contaminate a significant portion of the surrounding ground-water system (Quasim and Burchinal, 1970; Fungaroli and Steiner, 1971; Hughes, Landon and Farvolden, 1971; Rovers and Faquhar, 1973). Several costly methods have been developed to correct the pollution problem. The objective of these methods is either to retard the movement of fluids into and from the landfill (clay linings, asphalt linings, etc.) or to collect the leachate for treatment (Ludwig, 1967; Coe, 1970; Lessing and Reppert, 1971). An alternative could be to decrease the amount of water available for seepage by removing water from the landfill directly. Water can be removed conveniently and economically by using the roots of transpiring plants to dry the refuse and surrounding soil. Water removed by plant roots cannot contribute to leachate, and a drier landfill promotes aerobic decomposition (Moore, Molz, and Browning, 1974).

TRANSPIRATION

In areas of abundant rainfall, well distributed throughout the year, most plant species with equal leaf area will transpire at about the same rate (Linsley, Kohler, and Paulhus, 1958). Some variations in transpiration do exist, however, partly as a result of the differences in the length of the growing season for various species. When water supply is limited, depth and development of the root system are very important. Then, phreatophytes (plants whose root systems penetrate the water table) have a distinct advantage and may transpire 110 inches

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

[b] Respectively, Alumni Assistant Professor, Civil Engineering Department; Graduate Research Assistant, Civil Engineering Department; Agricultural Engineer, USDA, ARS, Auburn University Agricultural Experiment Station, Auburn, Alabama 36830.

(279.4 cm.) of water annually (Wisler and Brater, 1959), whereas shallow-rooted vegetation dies when surface soil becomes dry (Linsley, Kohler, and Paulhus, 1958; Wisler and Brater, 1959). Especially with commercial crops, transpiration ratios are used to characterize typical plant water use. These ratios are defined as the weight of water consumed to the dry weight of plant matter produced. A typical transpiration ratio for corn might average around 300, whereas that for alfalfa and cotton may average 850 and 600, respectively (Moore, Molz, and Browning, 1974).

Transpiration occurs mainly through pores found on leaf surfaces that are surrounded by special cells called "guard cells." These cells regulate the size of the pore openings (stomata) through which water vapor emission is largely confined and controlled. Among the environmental factors influencing transpiration are solar radiation, relative humidity, air temperature, and wind speed (Chow, 1964). Solar radiation is very influential since it stimulates the guard cells to open the leaf pores. About 95% of daily transpiration occurs between sunrise and sunset. Wind velocity also affects transpiration. Chow (1964) reported that with wind speeds of 5 and 15 mph (8.05 and 24.14 kmph), transpiration rates may be 20% and 50% higher, respectively, compared to zero wind speed.

Transpiration is one part of evapotranspiration; the other is direct evaporation. Although these are distinctly separate processes, they occur simultaneously, are difficult to separate, and both result in the transfer of water from soil to atmosphere. Consequently, medium- to large-scale measurements of water lost to the atmosphere are most often reported as evapotranspiration.

Historically, hydrologists have used lysimeters to measure evapotranspiration. Essentially, they are no more than upright tanks containing representative materials. Lysimeters maintain a water balance by enabling one to record the difference in weight or volume of liquid added as precipitation and that lost through seepage and evapotranspiration. Hence, lysimetry should offer a convenient way to evaluate the effect of evapotranspiration on leachate production by landfills. If transparent lysimeters were used, one could also study root growth in sanitary landfill materials, as described by Moore, Molz, and Browning (1974).

EXPERIMENTS AND RESULTS

To maintain a water balance so as to ascertain the effect of evapotranspiration (including interception) on leachate production, experiments were designed and conducted at the sanitary engineering field laboratory of Auburn University. Full-scale models of landfill cores were constructed (Figures 1 and 2), and, in the early spring of 1973, filled with a typical municipal refuse mixture (Bell, 1964; Moore, Molz, and Browning, 1974). Plant species, such as slash pine (*Pinus caribaea morelet*), black locust (*Robinia pseudoacacia* L.), thorny elaeagnus (*Elaegnus pungens* L.), bristly locust (*Robinia hispida* L.), and two grasses (*Lolium multiflorum* Lam. and *Eleusine indica* gaertn) were grown on two landfill models. A third was kept bare and used as a control. Facilities were designed to collect and hold any leachate produced at the base of the models for chemical analysis. All fluid volumes entering the surface and leaving the base of the simulated landfills were recorded, as were landfill temperatures.

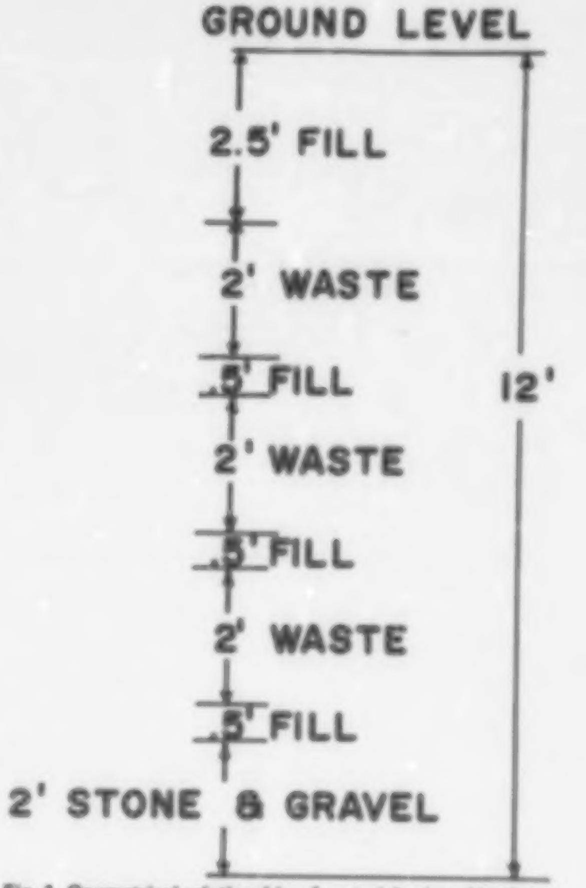

Fig. 1. Geometrical relationship of materials placed in the lysimeters. "Ground Level" refers to the top of the lysimeter which is 12 feet (365.76 cm.) above the actual land surface.

Thus far in the experiment, the species of selected plants have thrived, even though gas sampling indicated that the lower two-thirds of the

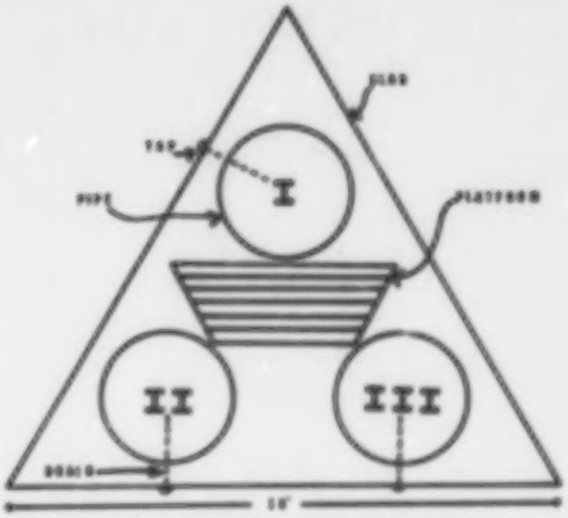

Fig. 2. Top view of the three lysimeters located at the Auburn University Sanitary Engineering Field Laboratory.

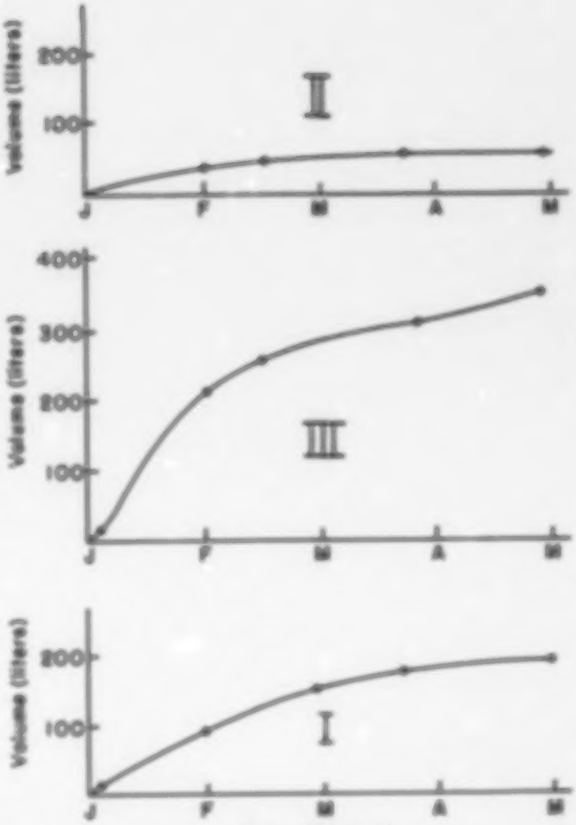

Fig. 3. Plot of cumulative leachate volume versus time for the three landfill models. Lysimeter III is fallow while lysimeters I and II are vegetated.

landfill models quickly became anaerobic (Moore, Molz, and Browning, 1974). Related studies using rectangular lysimeters with a transparent wall showed that roots rapidly proliferate through the top 2½ feet (76.2 cm.) of cover soil and first refuse layer. Below the first layer, roots grow more slowly. As of May 6, 1974, the landfill models had received 49 inches (124.46 cm.) of precipitation. After December 1973, a very wet month, all three lysimeters began producing leachate. However, the volume of leachate produced differed considerably, depending on whether the particular lysimeter was vegetated or fallow (Figure 3). To date, the unvegetated control (III) has produced approximately 394 liters (13.91 cu. ft.) of leachate, while the two vegetated models have produced 193 liters (6.82 cu. ft.) and 56 liters (1.98 cu. ft.) for I and II, respectively. Lysimeter II, which has produced the minimum leachate volume, is vegetated with slash pine and thorny elaeagnus, which are nondeciduous. The lysimeter producing the intermediate volume (I) is vegetated with black locust and bristly locust, both of which are deciduous. The fact that the thorny elaeagnus and pine form more dense annual cover accounts for the different volumes produced by the two vegetated models.

Table 1 shows a 6-month average of several chemical characteristics of the leachate collected from each landfill model. As expected, the unvegetated lysimeter produced the most dilute leachate. If one uses the chemical oxygen demand (COD), the total Kjeldahl nitrogen (TKN), and the total solids (TS) as indices representative of the potency of leachate, then the leachate from lysimeter II is, on the average, 1.97 times more concentrated than that from the fallow lysimeter III. Since the leachate volume from III is 7.04 times larger than the volume from II, one realizes a net improvement factor of 3.57 due to the presence of plants.

In addition to the potential for reducing leachate volume, landfill vegetation offers several

Table 1. Average Chemical Characteristics of the Leachate Obtained from Lysimeters I, II, and III

Characteristic (mg/liter)	*I*	*II*	*III*
Biological Oxygen Demand	11,422	9,236	2,167
Chemical Oxygen Demand	9,388	8,337	3,729
Total Carbon	5,723	5,314	2,381
Total Organic Carbon	5,613	5,180	2,093
pH	6.2	6.2	6.3
Alkalinity as $CaCO_3$	2,990	2,969	1,743
Total Kjeldahl Nitrogen	432	358	273
Total Solids	15,327	14,041	5,980

advantages. Plants such as thorny elaeagnus and pine can significantly enhance the beauty of a landfill site and help maintain property values in the landfill vicinity. In addition, vegetation retards erosion, stabilizes the landfill mass, and significantly reduces the rate of surface settlement. Thus, more consideration should be given to revegetating landfill areas with hardy, deep-rooting plants.

ACKNOWLEDGMENTS

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The writers would also like to thank Mr. Charles L. Moore for his many original contributions to the study reported herein.

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DISCUSSION

The following questions were answered by Fred J. Molz after delivering his talk entitled "Transpiration Drying of Sanitary Landfills."

Q. by Paul Plummer. *What was the discharge in Kg of the Total Solids, Total Kjeldahl Nitrogen and Chemical Oxygen Demand for each of the three lysimeters?*

A. As of September 15, 1974 the discharge from lysimeter I was: TS (3.14 Kg), TKN (0.089 Kg), COD (1.92 Kg). From lysimeter II: TS (0.87 Kg), TKN (0.022 Kg), COD (0.52 Kg). From lysimeter III: TS (3.38 Kg), TKN (0.20 Kg), COD (2.11 Kg).

Q. by Tim Bergin. *Is there any noticeable difference in refuse stabilization measured either by compaction or gas production?*

A. The fallow lysimeter is compacting more rapidly than the vegetated lysimeters, although we don't have exact measurements. However, the effect is substantial and of engineering interest. Also, there are higher oxygen concentrations in the vegetated lysimeters, but the effect is small.

Q. by Bob Hill. *What is the permeability of the fill between the waste layers in the lysimeters?*

A. The fill is a sandy-loam soil and is quite permeable. I would estimate the saturated permeability to be around 0.1 to 0.01 cm per sec.

Q. by Dale Mosher. *Could the more dense vegetation of pine and silver berry compared to the other lysimeters have caused a shedding of rainfall resulting in leachate quantity differences between the lysimeters?*

A. Measurements of interception in lysimeter II as compared to lysimeter III (fallow) indicated that as much as 30% of the rainfall was intercepted. This is a high value but does not include the water which runs down the stems of the plants. Thus the 30% figure can be considered as an upper bound. For our apparatus, I would think that 15% would be reasonable. Thus there appears to be a small shedding effect.

Q. by Don Langmuir. *Your trees are fairly small. Will larger trees with most of their root systems in the refuse be able to survive?*
A. I don't see why not. As the trees get older and the roots go deeper the landfill materials will have had time to stabilize and become less toxic. Of course we will have to wait and see to be sure.

Q. by K. Childs. *Isn't root penetration restricted by saturated conditions such as a water table? If so, would a landfill with a water table in it be unable to utilize plant roots for transpiration drying?*
A. Yes, some roots are restricted by a water table. With a water table in a landfill I would think that the benefits of transpiration drying would be reduced. Unless the aquifer was very impermeable, the ground water could supply all the water the vegetation required for transpiration and still saturate the refuse.

Ground-Water Quality Modeling[a]

by Lynn W. Gelhar[b] and John L. Wilson[c]

ABSTRACT

A generalized lumped parameter ground-water model is developed based on simultaneous water and solute balances for a phreatic aquifer. The basis for the lumped parameter approach is established by comparison with theoretical analyses of water and solute dynamics in a distributed aquifer model. The basic behavior of the model is characterized by two response times, one associated with the hydraulics and the other with the solute.

The model is applied to simulate the impact of highway deicing salts on ground-water quality in eastern Massachusetts. The results, obtained by digital computer simulation, are found to be in reasonable agreement with observed trends over a 15-year period. The effects of various highway deicing alternatives are simulated and the dependence on the aquifer parameters is demonstrated.

The application of this basin-wide modeling technique to the case of highway deicing salts demonstrates that this procedure can provide a reasonable basis for long-term evaluation of ground-water pollution. With adequate data on the inputs and aquifer parameters for a given locality, this general technique can be used to guide regulatory procedures and land use decisions which can be applied at the local, regional or State level to protect ground-water resources.

INTRODUCTION

The natural and generally high quality of ground water is under attack today by many sources and types of contamination which are associated with human activities and land use. Many incidents of contamination are geographically isolated and their sources, in the terminology of current federal legislation, may be considered "point" sources of pollution. Although locally important, contamination from these sources may not be significant on a ground-water basin-wide level. In contrast, for example, nitrates and pesticides from agricultural areas and nitrates leaching from dense populations of septic tanks originate, in effect, from distributed, or "non-point" sources of pollution and may have a significant impact on a ground-water basin. These distributed sources, which may be treated as being relatively constant over the entire basin, are often associated with local development and waste disposal policies. Thus, it is important that we take ground-water quality into consideration during the land use planning process.

To do this we must predict how a contaminant is transformed and transported in the subsurface environment, an objective which is usually achieved by modeling the ground-water system. In general, natural aquifer structures are complex, and because of this complexity, data on aquifer properties is usually limited and highly uncertain. The data limitation, as well as a requirement for efficiency, leads us to greatly simplify representation of the natural system. This paper describes a model which is simple to apply and requires only the most limited data. The model can become an important tool to aid in local planning and environmental analysis, wherein decisions must be made from the existing data base within a limited time frame. Generally in the planning process and particularly with ground-water pollution problems, the effects of our current decisions will be with us for decades, and thus we need models which can predict those long-term effects.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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Traditionally ground-water quality modeling has been based on distributed system representations of the ground-water flow; e.g., Maddaus and Aaronson (1972) used a computer based finite difference model of two-dimensional aquifer flow to predict quality trends throughout a ground-water basin. Lyons and Stewart (1973) developed a distributed two-dimensional finite difference aquifer model coupled with a storage effect for the unsaturated zone to predict TDS in a basin. Pinder (1973) used the finite element method to predict concentration distributions in an aquifer including the effects of hydrodynamic dispersion. Konikow and Bredehoeft (1974) have demonstrated the application of a numerical model which includes dispersion to water quality simulation in an irrigated stream-aquifer system, but the model requires extensive field data. Elaborate digital models have been used to evaluate the ground-water quality hazards of the AEC Hanford Project (Cearlock, 1971). Lumped parameter models have been used in predicting the salinity of irrigation return flows (e.g., Hornsby, 1973; Thomas, Riley and Israelsen, 1972).

The focus here is on the development of a general framework for a ground-water quality model which is simple and will be applicable especially when data on aquifer properties and extent may be limited. Since we are primarily interested in long-term basin-wide changes in ground-water quality due to distributed contaminant sources, we can ignore spacial variations and concentrate on the temporal variation of the mean contaminant concentration in the aquifer. This kind of model which ignores spacial coordinates is called a lumped-parameter model (see Domenico, 1972). It requires that we specify the nature of the input to the model, the nature of the output from the model, and the model itself which relates inputs, outputs and system states. Furthermore we have chosen a conceptual model based on a well mixed linear reservoir, a technique long used in analyzing surface-water systems. With this technique the inflow of a mass of water or contaminant is balanced by a change in reservoir storage and an outflow. Since the system is considered well mixed, the outflow water contains contaminant at the same concentration as the reservoir. This simplification of the real system to a linear reservoir model is certainly viable for an initial attack on a problem and it may prove to be a great deal more practical than the more sophisticated models for everyday use.

In the following, the elementary balance equations are first developed and then the model parameters are related to the properties of some simple distributed systems. The model is applied to simulate the effect of highway deicing salts and the results are compared with some observations in eastern Massachusetts.

THE WELL MIXED LINEAR RESERVOIR

An elementary representation of the ground-water flow in a phreatic ground-water system can be stated in terms of a water balance in the form

$$n \frac{dh}{dt} = -q + \epsilon + q_r - q_p \qquad (1)$$

where: h = average thickness of the saturated zone; n = average effective porosity of the aquifer, q = natural outflow from the aquifer per unit area; ϵ = natural recharge rate; q_r = artificial recharge per unit area; q_p = pumping rate per unit area; and t = time. As will be discussed in detail later, the outflow from the aquifer can be approximated by the linear term

$$q = a(h - h_o) \qquad (2)$$

in which a is an outflow constant and h_o is a reference level at which the outflow is zero as depicted in Figure 1. The reference level h_o could, in general, be time dependent to represent the fluctuation of water level in some body of surface water contacting the aquifer.

The model given by Equation 1 with the outflow in the form of Equation 2 is a lumped parameter model which is identified as a linear reservoir; this type of model with generalizations has been used extensively to describe surface runoff phenomenon (e.g. Chow, 1964, Section 14) but has received only limited attention in relation to subsurface flows (Kraijenhoff Van de Leur, 1958; Dooge, 1960; Eliasson, 1971).

Similarly, a mass balance for some contaminant of average solute concentration c (t) can be stated as

$$n \frac{d}{dt}(hc) = -ac(h - h_o) + \epsilon c_o + q_r c_r - q_p c - knhc \qquad (3)$$

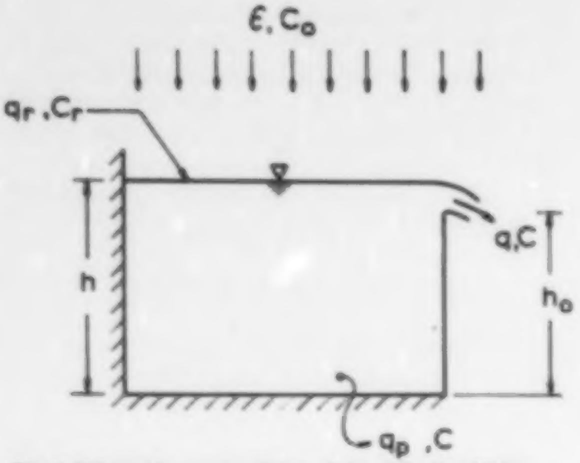

Fig. 1. Schematic representation of the well mixed linear reservoir.

where c_o and c_r are the concentration in the natural and artificial recharge respectively, and k is a first order rate constant which accounts for degradation of the contaminant. Equation 3 is based on the assumption that the system is thoroughly mixed, and thus the concentration in the outflow is identical to that in the aquifer. This assumption of complete mixing may at first seem inappropriate for a ground-water system; however, if input and withdrawals are distributed at numerous points throughout the aquifer this assumption becomes more reasonable. An explicit analysis of this approximation will be presented in the following section. A more convenient form of the mass balance is obtained by combining Equations 1, 2 and 3 in the form

$$nh\frac{dc}{dt} + (\epsilon + q_r + knh)c = \epsilon c_o + q_r c_r \qquad (4)$$

The system consisting of Equations 1, 2 and 4 is a lumped parameter model from which the time dependent features of water quality and quantity can be described for phreatic aquifers. In the following, some elementary solutions of these equations with $q_r = q_p = 0$ and h_o = constant will illustrate the general behavior of such systems. The water balance (Equations 1 and 2) will, after a long period, have a general solution in terms of the convolution integral

$$f = h - h_o = \int_{-\infty}^{t} \epsilon(\tau)\, u(t-\tau)\, d\tau \qquad (5)$$

where h_o is taken to be constant. The unit impulse of the system is given by

$$u(t) = e^{-t/t_h}/n\,, \qquad (6)$$

which is the solution when $\epsilon(t) = \delta(t)$, the Dirac delta function. The parameter $t_h = n/a$ is the response time of the water balance system. For a step input of recharge

$$\epsilon = \begin{cases} 0 & t < t_1 \\ \epsilon_o & t > t_1 \end{cases}$$

the explicit solution is

$$f = \frac{\epsilon_o t_h}{n}\,[1 - e^{-(t-t_1)/t_h}],\ t > t_1 \qquad (7)$$

and for a sinusoidal input

$$\epsilon = \epsilon_o(1 + \alpha \sin \omega t);\ \epsilon_o, \alpha, \omega = \text{constants}$$

the solution is

$$h - h_o = \frac{\epsilon_o t_h}{n}\,[1 + \frac{\alpha}{\sqrt{1 + (t_h\omega)^2}} \sin(\omega t - \phi)] \qquad (8)$$

where the phase shift ϕ is given by $\tan \phi = t_h\omega$. Note that the water-table fluctuation lags the recharge by an amount that increases with the response time t_h.

Similarly, if the water balance is steady ($\epsilon = \epsilon_o$ a constant, $h = h_o + \epsilon_o/a$) and the contaminant is conservative ($k = 0$), the mass balance (Equation 4) has the solution

$$c = \int_{-\infty}^{t} [c_o(\tau)/t_c]\, e^{-(t-\tau)/t_c}\, d\tau$$

where $t_c = n(h_o + \epsilon_o/a)/\epsilon_o$ is the response time of the mass balance system. For a step input of concentration c_o at time $t = 0$, the solution is, following Equation 7,

$$c = c_o(1 - e^{-t/t_c}),\ t > 0 \qquad (9)$$

For a linear increase in input concentration, $c_o = bt$, $t > 0$, b = constant, the solution is

$$c = b[(t - t_c) + t_c e^{-t/t_c}]$$

from which it is seen that, for large time ($t >> t_c$) the output concentration lags the input concentration by the response time t_c.

PHYSICAL BASIS AND PARAMETER ESTIMATION

The outflow parameter can be related to the usual aquifer parameters by considering the classical Dupuit approximation (e.g., Bear, 1972) applied to a stream-connected phreatic aquifer (see Figure 2). Using h (x) to denote the thickness of the saturated zone as a function of horizontal position, the steady flow equation is

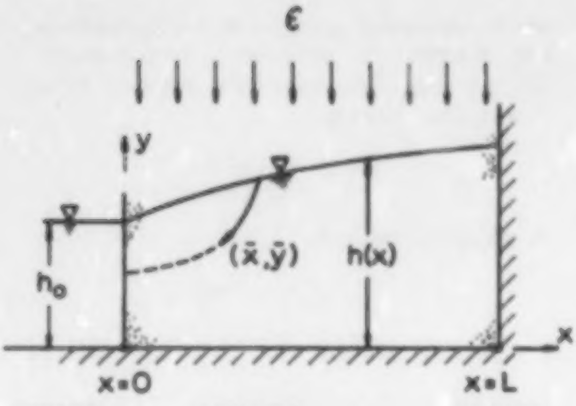

Fig. 2. Contaminant movement in an idealized phreatic aquifer.

$$\frac{d}{dx}\left(Kh\frac{dh}{dx}\right) = -\epsilon \qquad (10)$$

where K is the hydraulic conductivity of the aquifer and ϵ is the accretion or natural recharge rate. Applying the no flux condition at $x = L$, the solution of Equation 10 is

$$h^2 - h_o^2 = \epsilon x(2L - x)/K \qquad (11)$$

and when $h - h_o << h_o$ this is approximated by

$$h - h_o = \epsilon x(2L - x)/2T \qquad (12)$$

where $T = Kh_o$, the aquifer transmissivity. The average thickness of the saturated zone $\bar{h}$ is then

$$\bar{h} = h_o + \epsilon L^2/3T \qquad (13)$$

and under steady conditions the outflow from the aquifer per unit area is ϵ, so that the linear reservoir parameter a in Equation 2 becomes

$$a = 3T/L^2 \qquad (14)$$

For unsteady flow with a declining sinusoidal water table a similar analysis indicates that

$$a = \pi^2T/4L^2 \qquad (15)$$

Equations 14 and 15 can be used to estimate the response time $t_h = n/a$ if the lateral extent and the aquifer transmissivity are known or can be estimated. The response time can also be determined from spectral analyses of water level and precipitation data based on stochastic models developed by Gelhar (1974). The above analysis demonstrates that the average behavior of a stream-connected phreatic aquifer can be approximated by a first order lumped linear system as given by Equations 1 and 2.

The relation of the mass balance system (Equation 4) to a distributed phreatic system can be shown by analyzing the displacement of some contaminant through the aquifer illustrated in Figure 2. The kinematics of contaminant movement through the aquifer are determined from the steady flow field.

When $h - h_o << h_o$ the horizontal component of the specific discharge is

$$q_x = -K\frac{dh}{dx} = -\epsilon(L - x)/h_o = \frac{\partial\Psi}{\partial y}$$

where Ψ is the stream function. Integration yields the stream function

$$\Psi = -\frac{\epsilon(L - x)}{h_o}y$$

from which the vertical component of the specific discharge becomes

$$q_y = -\frac{\partial\Psi}{\partial x} = -\epsilon y/h_o \qquad (16)$$

The vertical position $\bar{y}$ of a particle which originates at the surface $y = h$ then is described by

$$\frac{d\bar{y}}{dt} = q_y/n = -\epsilon\bar{y}/h_on$$

which has the solution

$$\bar{y} = h(x)\,e^{-t/t_c},\; t_c = nh_o/\epsilon \qquad (17)$$

using the condition $\bar{y} = h(x)$ when $t = 0$. Similarly the horizontal position $\bar{x}$ is described by

$$\frac{d\bar{x}}{dt} = q_x/n = -\epsilon(L - \bar{x})/h_on$$

with the solution

$$L - \bar{x} = (L - x)\,e^{+t/t_c} \qquad (18)$$

where $\bar{x} = x$ when $t = 0$. Equations 17 and 18 give the location of particles which originate at the phreatic surface when $t = 0$. If the aquifer is initially uncontaminated and at time $t = 0$ the concentration in the accretion becomes c_o, then the boundary of the contaminated zone is described by Equations 17 and 18. When the water leaves the aquifer at the stream, $\bar{x} = 0$, and therefore the time required for a contaminated particle to reach the stream is related to its initial position x by

$$(L - x) = Le^{-t/t_c} \qquad (19)$$

Using Equations 12 and 19 in Equation 17, the vertical location of the contamination boundary as it reaches the stream is

$$\bar{y} = h_o[1 + (1 - e^{-2t/t_c})(\epsilon L^2/2Th_o)]\,e^{-t/t_c}$$

and when $h - h_o << h_o$, i.e., $\epsilon L^2/2Th_o << 1$, this is approximated by

$$\bar{y}/h_o = e^{-t/t_c} \qquad (20)$$

Because the horizontal component of the specific discharge is constant over the depth of the aquifer, the average solute concentration for the water leaving the aquifer is

$$c = c_o(h_o - \bar{y})/h_o = c_o(1 - e^{-t/t_c})$$

This result is seen to be equivalent to the solution of Equation 9 with the corresponding step input if the factor ϵ_o/ah_o is small in the response time expression preceding Equation 9. This will be the case when $h - h_o << h_o$ since a is related to the aquifer parameters by Equation 14. Using Equation 17, the average concentration in the aquifer is

$$\bar{c} = (c_o/L) \int_0^L (1 - \bar{y}/h)\, dx = c_o(1 - e^{-t/t_c})$$

which is identical to the concentration leaving the aquifer. These results show that, based on this analysis, both outflow concentration and the average concentration in the aquifer of the contaminant transport are equivalent to those obtained using the well mixed linear system introduced in the previous section.

In the above analysis it was implicitly assumed that dispersive mixing is negliglible. Eldor and Dagan (1972) analyzed the effects of dispersion in a very similar soil leaching problem and found that the result is "practically uninfluenced by dispersion." The lumped system will be most appropriate when the contaminant is widely distributed over the areal extent of the aquifer and when the average concentration of several wells or the concentration of the effluent to a stream is sought. The lumped model will not adequately represent the concentration in a single well especially if the source of contamination is very localized.

The analyses in this section establish the physical basis for the lumped water and mass balances in relation to a simple aquifer flow. Although in a natural setting there are several other complicating factors such as complex aquifer geometry and structure, anisotropy, dispersive mixing and partial penetration of stream which may influence the result to some extent, this elementary analysis illustrates the basic behavior of phreatic aquifers in terms of certain aquifer parameters. The two basic parameters in the water and mass balances are the response times t_h and t_c. It can be seen from Equation 4 that t_c is not, in general, a constant; however, its magnitude can be estimated from $t_{co} = nh_o/\epsilon_o$ where ϵ_o is the average inflow to the aquifer. Values of the two response times based on typical values of the aquifer parameters are shown in Table 1. These values illustrate the effects of aquifer dimensions on the response times. Usually the solute response time will be greater than the hydraulic response time but for relatively shallow aquifers the opposite may be the case. Estimates of response time are used in the simultaneous water and mass balance system (Equations 1, 2 and 4) as illustrated in the following sections.

Table 1. Typical Value of Response Times

Aquifer Thickness h_o *(ft)*	*Aquifer Length* L *(ft)*	*Hydraulic Response Time* t_h *(yr)*	*Solute Response Time* t_{co} *(yr)*
25	500	0.083	6.25
25	5,000	8.3	6.25
100	5,000	2.1	25
400	50,000	52	100

Note: Values based on ϵ_o = 1 ft/yr, K = 10^4 ft/yr, n = 0.25, $t_h = nL^2/3Kh_o$, $t_{co} = nh_o/\epsilon_o$.

NUMERICAL MODEL

Although the analytical solutions of the water and mass balance equations (Equations 1, 2 and 4) described above may be useful tools in understanding some features of a ground-water reservoir, they are too restricted to be of much use in dealing with real problems. In real problems there are a variety of inputs of both quantity and quality making it inappropriate, for example, to set $q_p = q_r = 0$ for the water balance and $\epsilon = \epsilon_o$ a constant for the mass balance. The natural recharge rate is generally a random function of time, and may also contain a deterministic component of time reflecting changing land use patterns. For example, as artificial drainage is improved, less precipitation eventually enters the ground water. The other inputs (q_r, q_p, c_r and c_o) are also functions of the changing pattern of land use. Although water may be purposely recharged through basins or pits, it is also recharged coincidentally with the growth of a septic tank population or with the development of a land-based sewage treatment project. The pumping rate is a function of the dependence of a community on the ground water for water supply and the growth of that community. The concentration of a contaminant in artificial recharge (e.g., nitrates in septic tank leachate) or natural recharge (e.g., highway deicing compounds) may also be a function of time.

These features are conveniently handled by stating the water and mass balance equations in finite difference form and solving the resulting equations numerically. For a change in time of Δt the water balance equation (Equations 1 and 2) may be written as

$$h_{i+1} - h_i = \Delta t[(h_o - \frac{h_{i+1} + h_i}{2})\frac{1}{t_h} + \frac{\epsilon_i + q_{ri} - q_{pi}}{n}] \qquad (21)$$

where the subscript i refers to the i^{th} time step, $t = i\Delta t$. Thus Equation 21 gives h at time i + 1 in terms of h and the inputs at time i. A similar expression for the mass balance (Equation 4) is

$$c_{i+1} - c_i = -\frac{\Delta t}{n}[(\epsilon_i + q_{ri})(\frac{c_{i+1} + c_i}{2}) - (\epsilon_i c_{oi} + q_{ri} c_{ri})](\frac{2}{h_{i+1} + h_i}) \qquad (22)$$

where the decay term in Equation 4 has been dropped. Equation 22 gives the concentration, c, of a conservative solute at time i + 1 in terms of h at time i + 1, as well as h, c and the input variables at time i. Since this is a linear model, it predicts the concentration of various solutes above that of the natural background concentration.

To apply the model to a particular area or region, specific inputs must be developed and the range and combination of parameters must be estimated. The following section contains a simple example illustrating how this can be done.

APPLICATION TO HIGHWAY DEICING SALTS

The effect of highway deicing salts, primarily sodium chloride, on ground water in eastern Massachusetts will be examined as an illustration of the application of the lumped parameter model. A significant portion of the applied salt will, after forming a brine with melt water, percolate to the ground water lying beneath highways and exposed salt piles. Where the density of roads is high, as it is in eastern Massachusetts, this winter application of salt can be treated as a distributed source of chloride ion.

The recommended limit for chloride ion in drinking water is 250 ppm (U.S. Public Health Service, 1962) although lower concentrations are desirable. This limit has been exceeded in several locations and is being approached in public water-supply wells in many built-up areas with extensive highway development (Arthur D. Little, 1972; Coogan, 1971; Environmental Protection Agency, 1971; Huling and Hollocher, 1972). There is little doubt that these increasing concentrations of sodium and chloride are due to the increased use of highway deicing compounds.

A number of estimates have to be made of land use and aquifer parameters, and of the various inputs to the model. In eastern Massachusetts the amount of water removed by pumpage varies from town to town but it certainly averages less than 2 inches per year. Much of this is recharged after use through septic tank leaching fields. In any case the net effect of these processes on the buildup of road salts in the ground water is minimal and it is reasonable to set $q_r = q_p = 0$ and $c_r = 0$.

The 2 important inputs for this problem are natural recharge, ϵ, and the concentration of solute in the recharge, c_o. In this illustration annual precipitation data from local climatological records constitutes the basic data from which recharge is estimated. The time step, Δt, in the numerical scheme is specified as one month. The annual recharge is taken to be proportional to the annual precipitation and is distributed over the first 5 months of the year in a triangular step-wise pattern typical of recharge in New England (see Huling and Hollocher, 1972). The maximum recharge occurs in March and no recharge occurs after May. Thus the total recharge in any month is given as $\epsilon = ABP$, where $A = 0.35$ is taken as the portion of annual precipitation going to recharge, P is the annual precipitation and B is the portion of annual recharge occurring in a given month (B = 0.08 in January and May, 0.24 in February and April, 0.36 in March and 0 the rest of the year). The 40-year record of annual precipitation for Worcester, Massachusetts is used for the precipitation input.

If all road salt applied to our highways is considered to be sodium chloride, the concentration of NaCl in the natural recharge (c_o) depends on the rate of natural recharge, ϵ; the density of highways, roads and streets in the study area; and the rate of application of salt to those roads. Representative data for several eastern Massachusetts cities and towns indicates that 8 to 10 tons of salt per lane mile were applied to municipal and town roads during the winter of 1970-71 (Arthur D. Little, 1972; Huling and Hollocher, 1972). The Massachusetts Department of Public Works reported that 23 tons per lane mile were used that same winter on State roads (Arthur D. Little, 1972). With an estimate of 5% of roads as State maintained, the average application rate of deicing salt in eastern Massachusetts during that winter was 12 tons per lane mile. Considering the highway network as a distributed source of salt contamination, these

Table 2. Basic Data for the Road Salt Model

	Population Density (persons/acre)	*Street Density (salted street area/basin area)*	*Street Density Exponential Growth Coefficient (per year)*	*Estimated Fraction of Salt Reaching Water Table*
Urban	86	0.15	1.3×10^{-3}	0.1
Heavy Suburban	20	0.10	3.7×10^{-3}	0.25
Light Suburban	5	0.05	1.5×10^{-3}	0.5
Rural	1	0.01	2.5×10^{-4}	0.5

linear application rates may be converted to rates in terms of a unit area of ground-water basin once the street density is known.

A recent State legislative report (Arthur D. Little, 1972) gives records of the amount of salt used by the Massachusetts Department of Public Works on the roads it maintained from 1955 to 1972. A tenfold increase in salt use is indicated during this time period, and a doubling from 1965 to 1972. The increase can be fit to an annual exponential growth rate of 0.1 per year.

Four different land use patterns were considered: urban (e.g., Boston or Cambridge); heavy suburban (e.g., Newton); light suburban (e.g., Concord) and rural. Land use data for Massachusetts (Comprehensive Land Use Inventory, 1965) was analyzed to determine typical street densities (area of streets and highways/ground-water basin area) for 1963 and street density growth rates for the period 1955-1963. This information, along with estimates for the percentage of total street area which is salted, as well as the percentage of road salts reaching the water table, is given in Table 2.

As seen in Table 2 the portion of the road salt reaching the ground-water reservoir is related to land use. Less salt infiltrates where drainage facilities are well developed, as in heavy suburban areas. From snowfall records it is evident that nearly all the salt is applied in the 4 months from December to March. Using an estimated time lag of one month involved in the brine water passing down through the soil to the water table, the actual recharge by contaminated water takes place from January to April, or during the first third of each year. Thus the amount of salt entering the ground water during a given month is assumed to be proportional to the natural recharge that month. Note that the natural recharge is assumed to be independent of land use, a situation which may be unrealistic for some applications.

Table 3. Aquifer Parameters

Aquifer Depth h_o *(feet)*	*Hydraulic Response Time* t_h *(months)*	*Aquifer Length** L *(feet)*
25	1	500
50	6	1,730
100	12	3,460

* Based on $K = 10^4$ ft/yr ≅ 200 gpd/ft^2, $n = 0.25$.

Three typical aquifer sizes were considered in this example with response times as indicated in Table 3. The average porosity was taken to be $n = 0.25$.

The numerical scheme was programed in BASIC and executed on a Hewlett-Packard Mini-Computer, Model No. 2114B, the type of inexpensive machine becoming widely available to many potential users.

A model simulation of water-table fluctuation with $h_o = 50$ feet and $t_h = 6$ months is compared to a local observation well record (Wilmington, Mass.) in Figure 3 for a typical 5-year period. A single well can be expected to present a better over-all picture of regional ground-water table fluctuations than it can of contaminant concentration fluctuation because the latter has a greater spacial variation. The simulation is based on the annual precipitation data with the recharge pattern as described above.

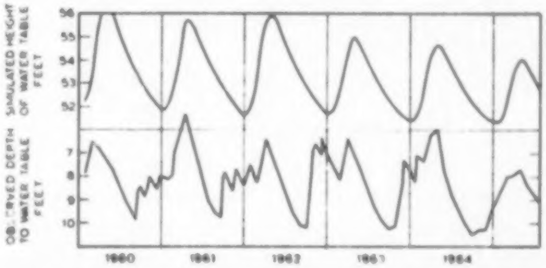

Fig. 3. Observed and simulated water levels; data from well no. 78, Wilmington, Massachusetts.

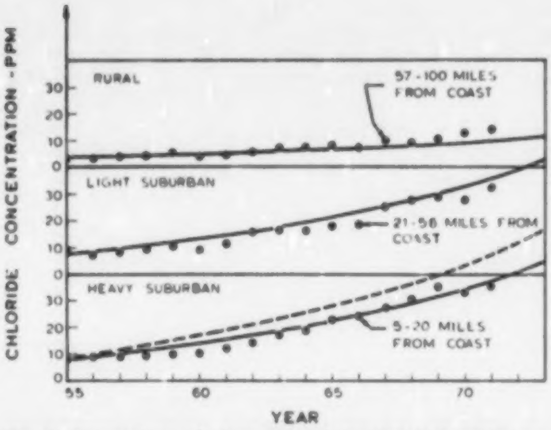

Fig. 4. Comparison of observed and simulated chloride concentration in ground waters of eastern Massachusetts; the solid line is the simulated April concentration for $h_o = 50$ feet, $t_h = 6$ months, the dashed line for $h_o = 25$ feet, $t_h = 1$ month and the circles are Coogan's (1971) data.

A comparison of the well record and simulation indicates that the model reproduces the general behavior of the water table, with the same late-winter, early-spring peaks, and the relatively low water table for the drought, beginning in 1965. However, the model does not simulate the much smaller fall recharge evident in some years because this feature was not included in the recharge distribution.

Figure 4 compares the predicted salt concentrations in various areas of eastern Massachusetts with field data compiled by the Massachusetts Department of Public Health (Coogan, 1971). Coogan's paper presents the average chloride concentration in public water-supply wells for the period 1890 to 1970. He found it convenient to divide the eastern part of the State into 3 bands: 5 to 20 miles, 20 to 56 miles and 57 to 100 miles from the coast. These bands correspond fairly well with the land use descriptions used here: heavy suburban, light suburban and rural. The data indicates that chlorides have been increasing above natural background levels since 1940. Starting with average chloride levels for 1952-1954, still relatively low, the model utilized the estimated parameters, including growth rates, in order to model this buildup of salts. The application rate in the base year, 1954, was taken as 2 tons per lane mile (Arthur D. Little, 1972), and the recharge was based on the Worcester, Massachusetts precipitation record, 1954 to 1970. The typical ground-water basin was estimated to have an $h_o = 50$ feet and $t_h = 6$ months.

Figure 4 illustrates that the basin-wide model can give fairly decent predictions of historical record. This is especially interesting considering that many of the model parameters (e.g., the recharge ratio) were not particularly chosen to fit Coogan's geographic divisions. Once provided with reasonable estimates for the parameters involved it is evident that the basin-wide model could be a simple, yet valuable tool for examining the effects of future road deicing policies on ground-water quality.

Figure 5 shows a buildup in salt concentration for a shallow aquifer ($h_o = 25$ feet) in a light suburban area (curve A), in a manner similar to the historical curve given in Figure 4. This assumes that salting is started in year zero at a base rate of 2 tons per lane mile and grows. Street density is also allowed to grow. At the end of 18 years the salting policy is reviewed due to the buildup of salt in the ground-water supply. Several alternatives are suggested and their results on the bulk salt concentration in the aquifer are illustrated. Alternative A is to continue past policy, and thus, past growth. Curve A leaves little doubt that this policy will soon result in the complete contamination of the basin with chloride levels beyond recommended water-supply limits. Alternative B is to abandon the use of road salts as highway deicers in an effort to clean up the aquifer. For this small aquifer the cleanup is relatively rapid, but such a policy might not serve the best interests of public safety. This leads to alternative C, an effort to stabilize the salt application rate of 12 tons per lane mile, the rate in year 18. Although street density continues to climb, a quasi-steady state concentration is reached at about 100 ppm, 20 ppm greater than the present value (year 18). Suppose studies have shown that the average yearly application rate may be reduced to 8 tons per lane mile without any decrease in public

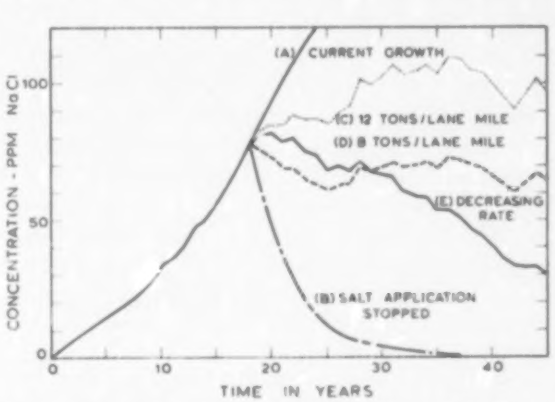

Fig. 5. Effects of alternative highway deicing policies for the light suburban area with $h_o = 25$ feet, $t_h = 6$ months.

safety. The result of such a policy is shown in alternative D with the quasi-steady value of concentration hovering around 65 ppm, a reduction of 15 ppm from the present value. Recall that these quasi-steady state values will experience long-term growth due to growing street density.

These last alternatives illustrate what may happen if we chose to continue salting at the same steady rate every year. If that rate is equal to or above present rates, we can expect the bulk concentration of salt in the aquifer to grow until it equals input concentration (curve C). If the steady rate is significantly lower, we can expect that the bulk aquifer concentration may reduce (curve D). Whether or not it will reduce in the near future will depend on the aquifer size. As shown in Table 1 larger aquifers have longer response times, indicating that even though the input concentration may decrease, the bulk concentration in the aquifer may continue to rise.

A final alternative considered here is to slowly decrease the rate of salt applied, from its value in year 18, while we find deicing replacements that are not harmful to the environment. Alternative E illustrates an exponentially decreasing application rate (0.05 per year). In connection with what was said in the previous paragraph, observe the rise in concentration, years 18 to 20, even as the application rate has been reduced. Such an effect is greatly magnified in a large aquifer.

Figure 6 illustrates the effect of alternative E on 3 different aquifer sizes. Although the bulk concentration in the larger aquifer builds up more slowly, it also decreases more slowly. Thus the large aquifer continues to experience an increase in salt concentration for 14 years after the change in policy, and does not return to its year 18 value until year 40. Although one type of alternative may appear most attractive for the small aquifer, it is obvious that the same set of alternatives must be reevaluated for larger ground-water basins.

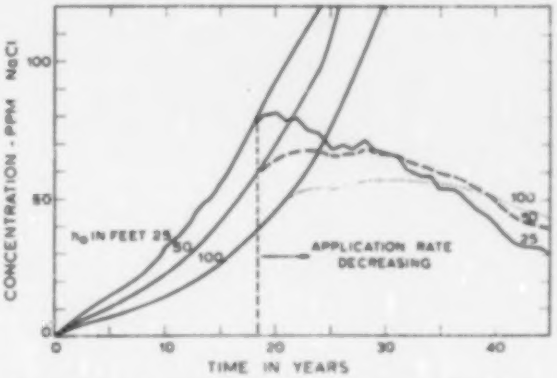

Fig. 6. Effect of aquifer size with a decreasing rate of salt application for the light suburban area.

CONCLUDING REMARKS

One important feature of the work is the elementary modeling structure which has been developed and applied. The lumped parameter model, based on simultaneous water and mass balances, is characterized by 2 physical parameters—the response times—which can be estimated from limited data. The equivalence of the lumped parameter model and a simple distributed system has been established.

The model was used to simulate the effect of highway deicing salts on ground-water quality in eastern Massachusetts and reasonable agreement with observed trends over a 15-year period was found. During this study the model was also used to simulate nitrate contamination from septic tanks and land-based sewage treatment (Gelhar, *et al.*, 1973), but no field data were available to evaluate those results. Additional evaluation of the model for other hydrologic conditions and water quality inputs is needed.

The application of the basin-wide modeling technique to the road salt example reveals that this general approach can provide a reasonable basis for long-term evaluation of ground-water pollution problems. The specific results developed depend on certain assumed hydrologic and water quality inputs. With adequate data on the inputs and aquifer parameters for a given locality, this general modeling procedure may be used to guide regulatory procedures and land use decisions which might be applied at local, regional or State levels to protect ground-water resources.

An important general feature which is brought out by this model is the slow response characteristics of ground-water systems. Especially in large aquifers there may be a substantial time lag between the concentration in the aquifer and the input concentration. In practical terms this means that the magnitude of developing ground-water pollution problems may not be adequately anticipated by monitoring ground-water quality. For a complete evaluation the over-all pollution loading on the system must be considered.

ACKNOWLEDGEMENTS

The paper developed out of a special 3-week course on ground-water pollution which was directed by the authors, at the Massachusetts Institute of Technology during the Independent

Activities Period, January 1973. The students participating in that course used the model to investigate several cases of ground-water pollution and thereby contributed significantly to the development of the model.

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Uniform Distribution in Soil Absorption Fields[a]

by R. J. Otis, J. Bouma and W. G. Walker[b]

ABSTRACT

The function of a septic tank-soil absorption system is to purify the wastewater discharged from the home before reaching the ground water. However, failure often occurs in the soil absorption field. Failure can originate from two causes: (1) inadequate infiltration of effluent into the soil, due to soil clogging or an increase in loading which results in surfacing septic tank effluent, and (2) inadequate purification in the soil during percolation because of short travel times which can be due to presence of very permeable, shallow soils or to local overloading. Inadequate purification may result in pathogenic pollution of private well-water supplies.

Failures of the second type can be prevented through proper design and operation of the soil absorption field. Studies have shown that 3 feet (90 cm) of unsaturated soil are adequate in purifying septic tank wastes with the exception of nitrogen removal. However, 4-inch (10 cm) diameter perforated drain pipe commonly used for distribution leads to local overloading near the point of inlet whereas other areas in the seepage system do not receive effluent at all. This leads to locally high flow rates of the waste through the soil reducing the soil's efficiency for pathogenic organism removal. Uniform distribution of the septic tank effluent over the entire soil absorption field is necessary to relieve this situation.

One method by which uniform distribution can be achieved over a large area is through a pressurized system. By properly sizing the diameters of the pipes and the number and diameter of the orifices in the distribution laterals, the head losses across the orifices will be great enough to cause the entire network to fill before the liquid is applied to the soil. This system combines the advantages of dosing with uniform distribution.

Three systems have been tested under laboratory and field conditions. The network is easy to manufacture and can be quickly sized. The design guidelines and results of laboratory and field testing are discussed.

INTRODUCTION

The failure of septic tank-soil absorption field systems serving homes in unsewered areas is a major concern with health officials because of the public health hazards that can develop. The function of the system is to purify the wastewater from a single home and recycle it to the ground water. However, failure often occurs in the soil absorption field. Failure can originate from one of two causes: (1) inadequate infiltration of effluent into the soil due to soil clogging which results in surfacing of septic tank effluent, or (2) inadequate purification in the soil during percolation because of short travel times, which can be due to the presence of very permeable, shallow soils or to local overloading. Because this latter type of failure cannot be observed visually it is often overlooked. However, inadequate purification may result in pathogenic pollution of private well-water supplies leading to severe public health problems.

Such failures can be prevented through proper design and operation of the soil absorption field. Studies have shown that 3 feet (90 cm) of unsaturated soil are adequate in purifying septic tank wastes with the exception of nitrogen removal (Magdoff *et al.*, 1974; Green and Cliver, 1974) but only if the soil is not overloaded. However, 4-inch (10 cm) diameter perforated drain pipe commonly used for distribution leads to local overloading near the point of inlet whereas other areas in the seepage system do not receive effluent at all (Bouma *et al.*, 1972, pp. 160, 224).

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Overloading results in locally high moisture contents in the soil with corresponding high-flow rates and short travel times through the soil. Processes of filtration, absorption and oxidation, which are essential to achieve purification, cannot operate effectively under these conditions. High-flow rates are therefore associated with poor purification and pathogens can move downwards for several feet (Bouma *et al.*, 1972, pp. 205-209; Green and Cliver, 1974). The problem is of particular concern in sandy, shallow soils with high permeabilities at saturation.

Application of effluent at acceptable rates for the particular soils is therefore essential for optimal soil absorption and purification of septic tank effluent. This paper will describe: (1) model experiments demonstrating the relationship between loading rate and associated travel times in underlying sand, which, in turn strongly influence the purifying potential; (2) design criteria for pressure distribution systems; and (3) field and laboratory tests of these systems.

LOADING RATES AND ASSOCIATED TRAVEL TIMES IN UNDERLYING SAND

The relationship between loading rate and corresponding travel time of effluent through underlying soil was investigated in a series of model experiments using Rhodamine dye. Two 60-cm (2 ft.) high columns with a diameter of 10 cm (4 in.) were filled with a medium sand. Moisture retention characteristics (desorption) are shown in Figure 1A and the hydraulic conductivity (K) curve is shown in Figure 1B. The column was saturated with water and was left to drain for 24 hours. Equilibrium moisture contents after drainage, as determined from the moisture retention curve and confirmed by *in situ* tensiometry, are shown in Figure 1C. The gravitation potential is in equilibrium with the matrix potential after drainage. In other words, the soil moisture tension at 10 cm (4 in.) above the bottom of the core is 10 cm (4 in.) and at 40 cm (16 in.) above the bottom it is 40 cm (16 in.), etc. The total volume of water in the column at equilibrium was approximately 900 cc (0.032 cu. ft.) and at a total pore volume of 1880 cc (0.066 cu. ft.), the air content was 980 cc (0.035 cu. ft.).

Seepage areas in sands are designed to receive 5 cm (2 in.) of effluent per day (Bouma *et al.*, 1972) which should ideally be distributed evenly over the entire seepage area during any 24-hour period. This is technically impossible and the

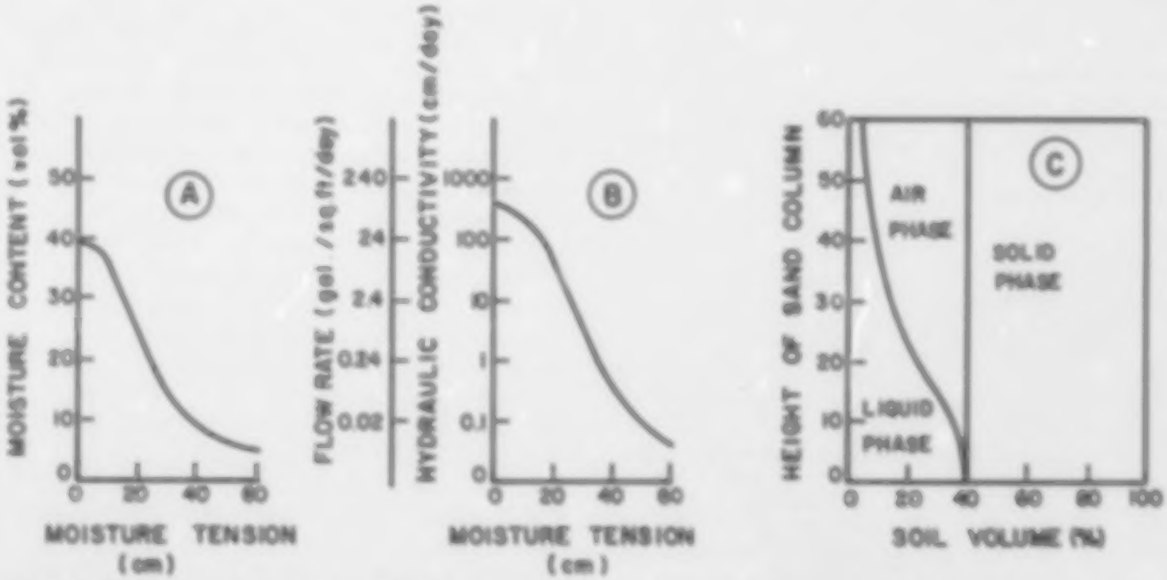

Fig. 1. Hydraulic characteristics of sand-filled columns: (A) moisture retention; (B) hydraulic conductivity; (C) equilibrium moisture contents.

Table 1. Data on Column Studies for Determining Travel Time of Dyed Water as a Function of the Dosing Regime

Exp. No.	*Volume of Daily Dose**	*Cumulative Outflow Before Dye Breakthrough*	*No. of Days Dosed*	*Retention Time of Dye in Column*
1	4000 cc (= 50 cm)	900	1	30 min.
2	500 cc (= 10 cm)	850	2	25 hrs.
3	400 cc (= 5 cm)	900	3	50 hrs.
4	200 cc (2½ cm)	920	5	100 hrs.

* 1 cm = 0.25 gal/sq. ft.

effluent is therefore applied by means of intermittent dosages. The sand located below an orifice in the distribution pipe is bound to receive the most effluent. The effect of local loading patterns on the flow regime in medium sand (Soil Survey Manual, 1951) was tested by repeated application of a specific volume of dyed water to a soil column containing undyed water at equilibrium. Repeated applications were made after re-establishment of hydraulic equilibrium. The time was noted when dyed water left the column for the first time. Volumes tested were 60 cm (25 in.); 10 cm (4 in.); 5 cm (2.5 in.); and 2.5 cm (1.25 in.). The columns were washed with clean water to remove the dye between tests of different volumes. Hydraulic equilibrium was re-established after approximately 4 hours when the latter 3 quantities of dyed water were applied.

Results of the tests are presented in Table 1, in which application of once-a-day dosages is assumed. Cumulative outflows before break-through of the dye of 850-920 cc (0.030-0.033 cu. ft.) were almost identical for all treatments and were approximately equal to the volume of water-filled pores in the soil under equilibrium conditions which was 900 cc. (0.032 cu. ft.). This illustrates that water applied to the column at equilibrium did not leave the column before all water present at equilibrium had left the column first.

This phenomenon can be explained by considering processes of capillary flow. Water applied to the sand will try to flow into the smaller pores because these pores exercise the largest capillary pull. However, these small pores are filled with water (Figure 1C), and water can only move into and through these pores if water leaves them at the bottom of the cylinder at a relatively low rate determined by their small size. Water will *only* move into and through large pores if the capacity of the smaller pores is inadequate to conduct the amount of water added. The physical properties of medium sand are such that water does not flow directly through larger pores. Instead the liquid flows through these finer pores, pushing the liquid out of the column that was present in the sand before dosing. Implications of these flow phenomena are important because longer travel times are bound to result in more effective purification. Preliminary results of associated bacteriological and virological studies, currently in progress, confirm this conclusion (Green and Cliver, 1974). Construction details of uniform distribution systems therefore have a direct relation to the degree of purification achieved by the underlying porous soil.

DESIGN CRITERIA FOR PRESSURE DISTRIBUTION SYSTEMS

One method by which uniform distribution can be achieved over a large area is to utilize a pressurized network. The liquid waste is pumped through a small-diameter perforated pipe rather than being allowed to trickle into the soil absorption field by gravity. The pipe network is designed such that most of the total energy required to deliver the waste to the trenches is lost across the perforations in the pipe. If this requirement is satisfied, the entire network will fill before much liquid is lost through the orifices nearest the pumping chamber.

Systems similar to this are used as backwashing systems for rapid sand filters in water treatment; therefore much design experience exists. Design variables include orifice diameter, number of orifices, lateral diameter, manifold diameter and pump discharge head. Balancing these variables to design a satisfactory system is a difficult task so design guidelines have been developed. These can be found in any text dealing with rapid sand filter design. Typical guidelines are given below (Fair, Geyer, and Okun, 1968):

1. The diameter of orifices should be ¼ in.-¾ in. (0.6 cm-1.9 cm).
2. The ratio of cross-sectional area of the laterals to the total area of the orifices served should be (2-4):1.
3. The ratio of the cross-sectional area of the manifold to the total cross-sectional area of the laterals served should be (1.5-3):1.

If these rules-of-thumb are followed closely and a sufficient head of water applied, uniform distribution will be achieved.

FIELD AND LABORATORY TEST OF THREE PRESSURE DISTRIBUTION SYSTEMS

To demonstrate the effectiveness of pressure distribution networks, 3 private homes were selected for installations. One site has a shallow permeable soil over creviced bedrock and the other 2 sites are located in slowly permeable soil areas. Mound systems were installed at 2 of the sites and a shallow trench system at the other.

Site I

The problem of ground-water contamination by pathogenic organisms is an acute problem in the Door County peninsula of northeastern Wisconsin. The county is underlain by creviced limestone with a very thin cover of porous soil. Bacterial and viral contamination of private well-water supplies traced to septic tank systems have plagued the region for many years.

In an effort to combat the problem, mounded or fill disposal systems have been installed. Details of these systems are given by Bouma, *et al.* (1974b). The principle of the mounded systems is to bring in additional soil material, usually a medium sand, and mound it over the area to be used for soil absorption. The seepage trenches are constructed within the fill. This provides the necessary 3 ft. (90 cm) of soil that column experiments indicated is sufficient for good purification (Magdoff *et al.*, 1974). However, monitoring of a mound designed by a local plumber indicated that adequate purification of the percolating effluent was not taking place. Bacterial counts of 300 coliforms per ml, 25 fecal coliforms per ml, and 100 fecal streptococcus per ml were found in the soil material below the mound. This was attributed to poor distribution of the septic tank effluent through the conventional 4-in. (10 cm) perforated pipe (Bouma, *et al.*, 1972, pp. 205-211).

To test this hypothesis, a single private home was selected for installation of a similar mound. To provide uniform distribution a pressurized system was constructed through trial and error. It consists of a 1¼-in. (3.1 cm) diameter plastic pipe leading into a 1-in. (2.5 cm) manifold and four 1-in. (2.5 cm) PVC laterals. Six ⅕-in. (0.51 cm) diameter holes are located 30 in. (75 cm) apart in each lateral. A laboratory test of the system showed good distribution during dosing (Bouma *et al.*, 1974b). Effluent is pumped into the mound 4 times daily.

This system has been operating since the summer of 1972. Monitoring of the liquid below the mound on a regular basis showed average counts of 54 coliforms per ml, 0.5 fecal coliforms per ml, and 0.1 fecal streptococcus per ml (Bouma *et al.*, 1974b). These results indicated that uniform distribution is essential for the proper functioning of these systems.

Site II

A second private home was selected for installation of a pressure distribution system in a slowly permeable soil area. It was felt that uniform distribution would also have application in tight soils by preventing local overloading of the soil by the liquid and solid phases of the waste. This combined with dosing could conceivably prolong the life of the field. While this has not yet been borne out, this installation did provide an opportunity to develop design criteria of pressurized networks and operational experience.

The home is occupied by a family of 5. A daily flow of 250 gal (946 l) was estimated based on 50 gpcpd (189 l/cap/day) (Bailey *et al.*, 1969; Witt, 1974). Percolation tests were run at the 2 foot depth and found to be 75 min/inch (30 min/cm). The crust test (Bouma, *et al.*, 1974a) was also performed. A saturated hydraulic conductivity of 5 cm/day (1.2 gal/sq. ft./day) was found. With aging of the infiltrative surface the hydraulic conductivity was expected to drop to 1 cm/day (0.24 gal/sq. ft./day). Subsequent *in situ* measurements of moisture tensions below the bed made after one year's operation proved this to be correct.

The soil absorption field was designed on the basis of 250 gpd (946 l/day) and a soil infiltration rate of 0.25 gal/sq. ft./day (1 cm/day). Considering bottom area only, a 1000 sq. ft. (92.9 sq. m.) system is required. A trench design of the field was used. Six parallel trenches 4 ft. × 42 ft. (1.2 m × 12.8 m) spaced 14 ft. (4.3 m) on centers with a central connecting trench 4 ft. × 75 ft. (1.2 m × 22.9 m) provide 1212 sq. ft. (112.6 sq. m.) of bottom absorption area. The trench bottoms are level and within the top 18 in. (45 cm) of the soil surface. The central trench receives no effluent directly but may accept any which flows from the parallel trenches. The trenches were filled with 12 in. (30 cm) of ¾ in.-1 in. rock (1.9 cm-2.5 cm) upon which the distribution network lies. This provides up to 1068 sq. ft. (99.3 sq. m.) of sidewall area (see Figure 2).

The pressure distribution system was designed following the design rules-of-thumb developed for rapid sand filter backwashing systems listed above. It was felt that the perforations in the pipe should be no smaller than ¼ in. (0.6 cm) in diameter and

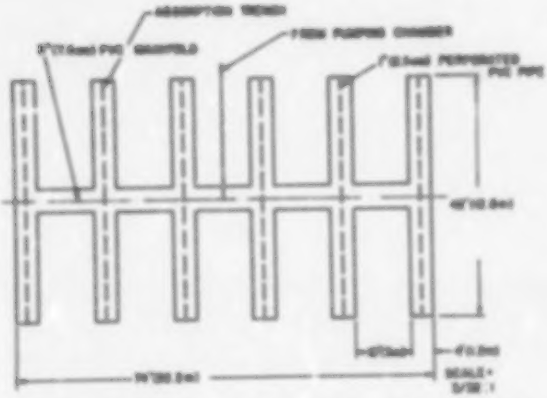

Fig. 2. Layout of pressure distribution system at Site II in slowly permeable soil.

all pipe diameters no smaller than 1 in. (2.5 cm) in diameter to prevent clogging by any solids in the effluent. Further, it was felt that the perforations should be spaced no greater than at 30 in. (75 cm) and soil trench widths should be no wider than 4 ft.(1.2 m) to ensure the entire trench bottom area was utilized. A lateral cross-sectional area to total orifice area ratio of 2 to 1 was used allowing 8 perforations per lateral. These were spaced at 30-in. (75 cm) intervals giving a total lateral length of 20 ft. (6.1 m). If 4-ft. (1.2 m) trench widths were to be used, this required 12 laterals to be provided. Using a ratio of the manifold cross-sectional area to the total cross-sectional area of the 12 laterals, a 4.24-in. (10.61 cm) diameter manifold is required. This was felt to be excessive because of the large volume and cost, so 3-in. (7.5 cm) diameter was tried. PVC pipe was used throughout.

Before installation of the distribution network it was assembled and tap water pumped through it at the expected rate of flow. The effectiveness of the system was observed only visually (see Figure 3). Within 10 seconds from the start of pumping the complete system filled and uniform distribution was achieved. The orifices nearest the manifold were observed to discharge more liquid at the beginning and end of runs; thus it was decided to include additional trench bottom areas under the manifold to accept this liquid.

The entire treatment and disposal system was installed in Summer 1972. The laterals were laid so that the perforations were on the underside of the pipe. The network was covered with an additional 2 in. (5 cm) of rock and the trenches are backfilled with topsoil to 12 in. (30 cm) above the original grade. To prevent freezing, the manifold was sloped back to the pumping chamber to allow complete drainage between pumpings. A common household ½-horsepower submersible sump pump is used in the pumping chamber.

Two 4-in. (10 cm) vertical perforated pipes were set in each trench, 14 ft. (4.3 m) from either side of the manifold. The pipes are 4 ft. (1.2 m) long and extend to the soil surface at the trench bottom. They were capped with standard vent caps. These are used as a means to sample and measure the liquid in the trench (see Figure 4).

Construction was done under ideal conditions. The soil was dry and because of the trench design the infiltrative surface was never compacted by machinery driving over it. Unfortunately, before additional fill could be brought in to mound over the system to promote runoff, heavy rains continued for 2 months. Total rainfall during that period was 12.13 in. (30.3 cm). The result of the rain was to completely fill the trenches so that surface seepage occurred during that Fall and the following Spring. During Winter 1972-73 the field was inspected but no seepage was observed.

In Summer 1973 the additional fill was added and surface seepage has not been observed since. The trenches have remained ponded, however. The water level is measured periodically showing a drop during the growing season and a rise during the Spring and Fall.

A portion of the system was dug up after a year of observation to determine if any of the orifices were clogging. It was felt that clogging might occur as the result of solids plugging the openings or from mineral precipitation. Neither was observed. The system continues to operate satisfactorily after 2½ years.

Site III

A third home occupied by a family of 5 was selected for a demonstration installation in another

Fig. 3. Hydraulic test of distribution system no. 2.

Fig. 4. Installation of network before backfilling at Site II.

slowly permeable soil area. In this case a mound was installed because of a seasonally perched water table. Details of its design and installation are given elsewhere (Bouma *et al.*, 1975). The mound is 70 ft. × 80 ft. (21.3 m × 24.4 m) with a medium sand used as the fill material. While saturated conductivity of the sand is approximately 200 cm/day (48 gal/sq. ft./day), the ultimate acceptance rates of infiltrative surfaces in sand have been shown to be reduced to 5 cm/day (0.24 gal/sq. ft./day) after septic tank effluent application (Bouma *et al.*, 1972). To estimate the daily flow 75 gpcpd (284 l/cap/day) was used to provide a safety factor of 1.5 which was felt to be necessary after the experience gained at Site II. Thus a trench bottom area within the fill of 300 sq. ft. (27.8 sq. m.) was required. This was provided by three 2.5 ft. (90 cm) wide trenches each 44 ft. (13.4 m) long. No trench was dug under the manifold in this installation. The total bottom area is 330 sq. ft. (30.7 sq. m.). The trenches were filled with 8 in. of ¾ in.-1 in. (1.9 cm-2.5 cm) gravel before the pipe was laid. This allows 187 sq. ft. (17.4 sq. m.) of sidewall area (see Figure 5).

Following the success at Site II, the same rules-of-thumb were used for the design of the pressure distribution network used in the mound. Six laterals 1 in. (2.5 cm) in diameter with ¼-in. (0.6 cm) diameter holes spaced 30 in. (75 cm) apart were used. These are identical to those at Site II. Using a ratio of 1.5 to 1 of the manifold cross-sectional area to the total lateral cross-sectional area requires a 3.67-in. (9.19 cm) diameter manifold. A 3-in. (7.5 cm) diameter manifold was used. PVC pipe was also used here for the network.

A common ⅓-horsepower submersible sump pump was again used in this installation to pump

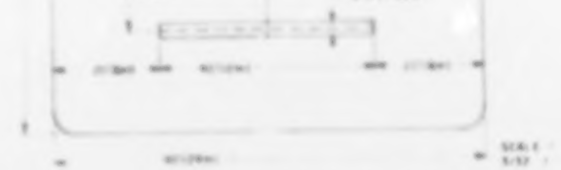

Fig. 5. Layout of pressure distribution system in mound at Site III.

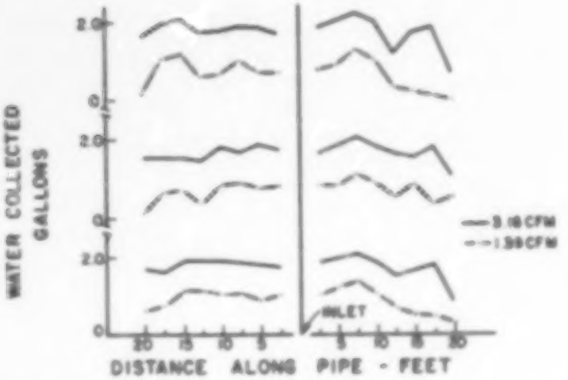

Fig. 6. Results of hydraulic testing of distribution system no. 2 (after Converse, 1974).

septic tank effluent to the mound. The pump operates off a mechanical float switch set at approximately 70-gallon (265 l) cycles.

This network was assembled and tested before installation by Converse (1974). Tap water was pumped through the system at rates ranging between 1.39 and 3.44 cfm (39.4 l/min-97.4 l/min). A pan was placed under each hole and weighed before and after every run to determine the volume of water discharged from each orifice. The results of this testing are shown in Figure 6. It was found that at the lower flow rates the end of the laterals received less flow but that the system provided much better distribution than conventional systems.

Installation of this system was completed in October 1973. The system operated satisfactorily until April 1974 when it was observed that the last trench was dry while the 2 upstream trenches were filled. Both ends of the manifold were located and the screw plugs removed. The manifold was clean except for less than 250 cc (0.07 gal) of sludge at the downstream end. The ends of the laterals in the last trench were then uncovered and cut open. These were found to be completely filled with sludge composed mostly of grease balls and sand (see Figure 7). This material had clogged the end lateral. The pump was activated and the laterals were flushed.

The reason for the high number of solids being discharged to the mound was due to a number of unusual circumstances related to improper maintenance by the homeowner which have been correct-

Fig. 7. Lateral clogged with grease and sand at Site III.

ed. One correction made which is felt to be important in all installations is to set the pump off the sump floor. When the pump was originally installed, this was not done. All other installations have had the pump set up on an 8-in. (20 cm) block, allowing for settling of any solids that are carried over into the sump. Placement of the pump was corrected, and in addition, the low water switch was set well above the pump volute to prevent any floating material from being pumped out. No further problems have occurred with this installation since these corrections were made.

COSTS

The cost of these systems ranges from $125 to $200 for materials. Approximately 2 hours are required for assembly. While this is about twice the cost of materials for conventional systems, installation is simplified since the distribution laterals need not be set on any grade or carefully leveled. All other details of construction are identical to conventional soil absorption systems.

CONTINUED RESEARCH

Additional laboratory studies are being conducted at the present time with full-scale models of several distribution systems. Pump discharge head, dose volume, manifold diameter and length of laterals are parameters being varied to determine their relationship to equal distribution.

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DISCUSSION

The following questions were answered by R. J. Otis after delivering his talk entitled "Uniform Distribution in Soil Absorption Fields."

Q. by Ken Childs. *Your talk equates purification with size terms—sand, clay, loam. How does the difference in chemical make-up of the soil affect purification? Does purification as you use it, refer only to bacteria? If so, why not include* NO_3^-, Cl^-, $SO_4^=$, *etc.? Why use the term absorption instead of adsorption?*

Q. by K. Jack Kooyoomjian. *Isn't the mechanism properly entitled soil adsorption instead of soil absorption? While some absorption does occur adsorption is the primary mechanism involved.*

A. When disposing of effluents into the soil two problems are faced, (1) getting the liquid to infiltrate the soil, and (2) purifying the waste. The first is a problem of soil absorption and does not refer at all to mechanisms of purification. The achievement of purification is dependent on many mechanisms including degradation, filtration, adsorption, predation and dilution. It is hoped that both these problems can be eliminated with improved distribution.

The case studies discussed in my presentation were particularly interested in pathogenic organism removal through porous soil systems. Movement of salts we were not particularly interested in though we recognize that it is a problem. Other research in progress in the Small Scale Waste Management Project is developing methods of N and P removal.

Q. by G. Morgan Powell. *What is the pressure and pumping rate?*
Q. by G. F. Hendricks. *What is the design head of the system?*
A. The maximum pressure achieved in these systems is about 0.5 psi. The pumping rate is approximately 15 to 20 gpm. We have found that larger pumps probably should be used.

Q. by Greg Stockert. *Is the pressure constant? If not, has there been overloading caused by the fluctuation of pressure in the system? Is pressure maintained on the system by a sensing device that turns on and off the pump?*
A. No attempt is made to maintain constant pressure through a pumping cycle. The orifices nearest the manifold will discharge more liquid at the beginning and ends of runs but this is not felt to be critical. The intent in the design of these systems is to provide improved distribution to prevent gross overloading while keeping the system simple and inexpensive.

Q. by Timothy J. Bergin. *What do you recommend the cycle time of the pump to be? Do you feel that there is any benefit in resting the field?*
A. We recommend that fields be dosed 4 or more times daily in porous soils and about once a day in tight soils. The more frequent dosing is necessary in the porous soils to prevent saturated conditions from developing which allow easy transport of pollutants. Less frequent dosing is recommended in the tighter soils to permit the soil to drain and rest between applications.

Q. by Robert D. Mutch, Jr. *Can the pressure distribution system operate effectively as a typical gravity system in the event of pump failure?*
A. No. We feel this will encourage the homeowner to repair his system. If it were to continue to operate after pump failure there would be little incentive to replace the pump until it was too late.

Q. by Dennis E. Gray. *Your slides indicate that the filter media is a sand gravel mix. Is this the way it was or did sand migrate down during excavation?*
A. The sand migrated down while digging the observation pits.

Waste Surveillance in Subsurface Disposal Projects[a]

by Raphael Kazmann[b]

ABSTRACT

Probably the most time-consuming procedure associated with a deep-well disposal project is found in the follow-up, when the operation is monitored to make sure that the injected material has not escaped from the target aquifer.

The usual procedure is to monitor the pressure in the annular space between the injection tubing and the exterior well casing, to monitor the injection pressure and, in extraordinary circumstances, to monitor water levels in an observation well in the nearest aquifer above the one used for disposal. This observation well is normally drilled at a distance of 300 feet or more from the waste-injection well and the theory is that if any of the injected waste is escaping from the target aquifer, this transfer of fluid into the upper aquifer will show up as a pressure increase, as compared to the base line data obtained before injection started.

Now there may, indeed, be a slow rise in pressure in the observation well. However, it may be so slow and so small that many years may elapse before it can be conclusively demonstrated that the pressure rise has actually occurred. Then the problem is: Where is the leak and what can be done? The reason for the tardiness in detection is that the observation well will most likely be affected by barometric changes, and these obscure the rise in pressure (water level) caused by the leak. Moreover, if the leak occurs at some distance from both the observation well and the injection well (and this is likely), the rate of fluid escape may be very small, possibly in the order of one percent or less of the injection rate. So if the injection rate is on the order of 700 gpm, we are talking about detecting the escape of 7 gpm of fluid at a distance of many hundreds of feet from the point of observation—an unlikely prospect.

The experimental and theoretical work now underway at Louisiana State University may point the way to effective waste monitoring and provide criteria which will lead to the safe containment of wastes for periods comparable to those used by geologists: from 10,000 to 100,000 years.

Our experimental work has shown that if the waste is denser than the native fluid in the aquifer (chemical compatibility, non-plugging, safe injection pressures, etc., being assumed), then, in a horizontal aquifer, where the waste may move radially from the injection well, due to the density difference (even though the injection well is completely penetrating) the waste tends to move to the base of the receiving formation. In fact, if the injection rate and the aquifer characteristics are known (or can be estimated to within, say, a factor of 2 or 3) then the maximum distance of travel along the roof of the aquifer can be computed. This implies that if a leak should occur in the confining bed at a greater distance than the computed maximum, the fluid leaving the target aquifer might not be waste, but might well be the brine contained in the target aquifer, presumably a much less dangerous substance.

If our objective is to determine the position of the waste front at any time after injection has begun, then it will be necessary to drill monitor wells in the target aquifer and to make multiple completions in the target aquifer from which samples of fluid may be obtained. The question then becomes: Where, and at what depths, shall the well be located and the multiple completions made? Our computational program is designed to answer these questions. The precision of the results depends on the validity of the data that is read into the program. We have verified the computational procedure on a miniature well field that is installed on a miniature aquifer (miniaquifer) in the laboratory, where all of the variables have either been determined or are under our control. Thus the simplest case of injection into a horizontal aquifer at a constant rate has been studied experimentally and we have made 3-dimensional models of the configuration of the waste after stated periods of time.

However, aquifers are seldom horizontal and they usually have fluid moving within them (there is a slope to the potentiometric surface). We are working on the computational programs that will take the initial movement of ground water in the aquifer into account if the aquifer is horizontal. We are also working on other programs which take dip into account both in the presence of ground-water movement or in its absence. All of these computational results have been, and will be, tested experimentally by injection projects in the miniaquifer. However, even before

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the mathematical models have been completed, some very useful qualitative results have been obtained.

Among the most important of these is the conclusion that a gently dipping aquifer, with no existing ground-water movement, is a desirable target aquifer—particularly if the waste is, or can be made, denser (higher specific gravity) than the native water. Under such conditions, the volume of pore space available between the injection well and the nearest down-dip boundary, will govern the minimum safe period of containment.

The recommendations for long-term waste disposal, including monitoring, involve adequate hydrogeologic evaluation of the containment aquifer prior to building the waste disposal well. Although the initial cost of such a project may be increased over costs now prevailing, a single adequate study will make it possible to design more than one disposal project in an area and make it possible to protect the biosphere from the effects of noxious wastes for a period further into the future than the time interval between the construction of the first of the pyramids in Egypt and the present day.

The injection of wastes through deep waste-disposal wells has always included monitoring as part of the process. However, for most part the object of the monitoring has been to ascertain whether or not the wastes have escaped either from the well or from the target aquifer into adjacent formations or the biosphere. Thus injection pressures are continuously recorded as are rates of injection; the pressure of fluid in the annulus between the injection string of tubing and the well casing is watched so as to detect tubing leaks and, rarely, the water levels or pressures in an overlying formation are checked to detect pressure changes that might be due to leakage of waste through a crack or fissure of the confining bed (Goolsby, 1972, p. 359; Talbot, 1972, pp. 85-92).

Although current procedures have proven to be generally satisfactory, the operating experience of some of the oldest installations is less than a decade in duration and of the estimated 2,000 waste injection wells now (1974) in operation, all but 35 have been built since 1962.

This short-lived experience with subsurface waste disposal contrasts with the permanent presence of the exotic, injected wastes—from pickling liquor to radioactive material—in the subsurface environment. For the sake of our own, and future, generations we are justified in adopting the "long view" in waste management with a time horizon of a thousand years or more.

From such a viewpoint our information should be of a positive nature; we should be actively interested in where the waste actually is at any time. The current attitude, that things are going well if we can be sure that the waste stays in the target aquifer and does not contaminate presently and potentially useful subsurface resources, should be modified and extended. Exploratory testing and monitoring programs should be designed to evaluate the target aquifer as a container for waste and to enable us to keep track of the movement of the waste for many years after injection has started. We should be able to predict where the waste will move to, how fast it will move, and when it will arrive at one or more predetermined check points.

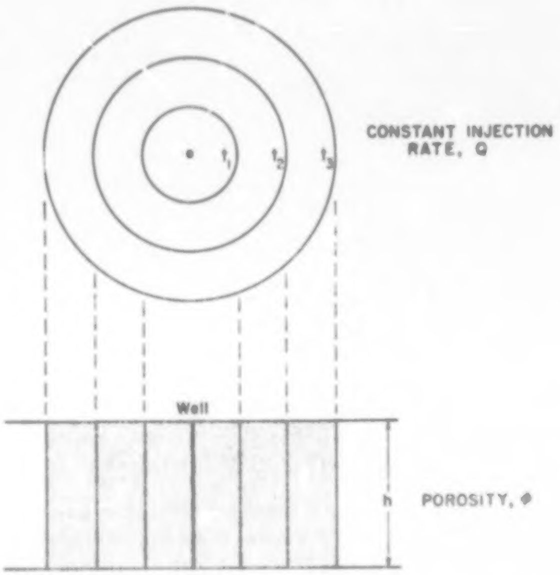

Fig. 1. Successive positions of waste front (t_1, t_2, t_3) after different intervals of waste injection.

The usual method of computing the capacity of an aquifer to accept waste is volumetric; assume piston-displacement of the native water, then the cumulative volume of waste injected is $\pi r^2 h\phi$, or a cylinder of aquifer, radius r, thickness h, and porosity ϕ. This visualization is a misleading one, but it can be depicted schematically as in Figure 1.

Based on such a picture, the monitoring of waste after it has been injected is readily accomplished; place one or more observation wells at different distances from the injection well and then the cumulative quantity of waste injected will be equal to the average rate of injection, Q, multiplied by the period of injection, t, and this, in turn, will be equal to the volume of the cylinder whose height is h, radius r, and porosity ϕ:

$$Qt = \pi r^2 h\phi \qquad (1)$$

For any particular distance the time needed for the waste front to arrive can be readily computed.

There are several important omissions in this

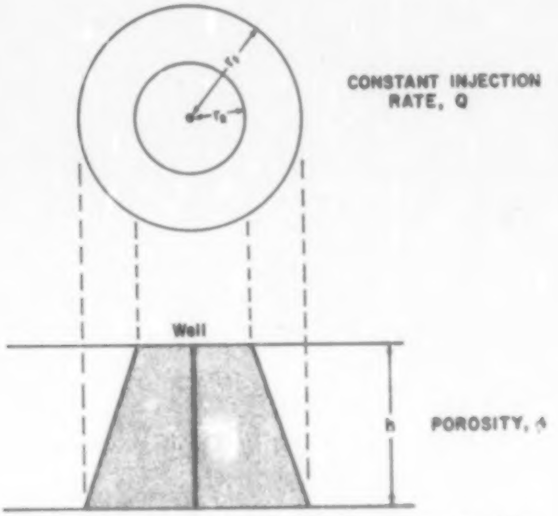

Fig. 2a. Schematic diagram showing effect of density difference on the shape of the injected waste (r_R has reached its maximum, r_F is still growing).

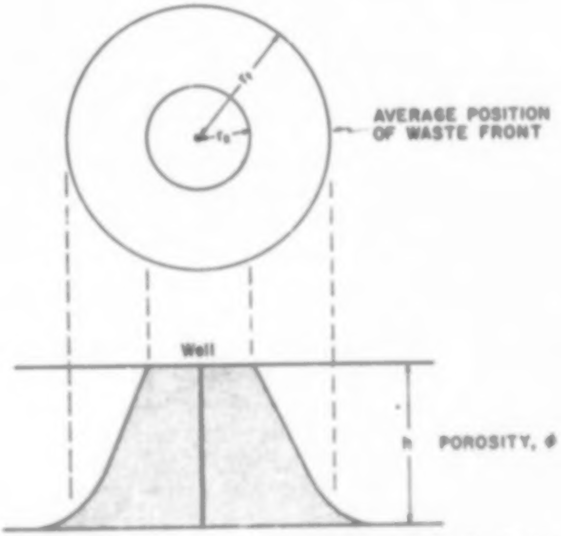

Fig. 2b. Schematic diagram showing effect of density difference on shape of the waste body after a long period of injection (r_R has reached its maximum, r_F is still growing).

visualization. First, what if the density of the waste is different from that of the native ground water? Even though the aquifer is horizontal, homogeneous, and isotropic, if the waste is denser than the native water it will tend to settle to the floor of the aquifer (if less dense it will float to the roof of the aquifer). Moreover, after a period of injection, when peripheral area of the slug of injected waste reaches a critical value, the rate of descent to the floor will equal the injection rate and the trace of the upper part of the waste will reach a maximum while the floor contact continues to expand. Again, simplifying matters for purpose of explanation, the situation can be best visualized by a study of Figures 2a and 2b. In Figure 2a the contact circle between aquifer roof (r_R) and waste has reached a maximum. However, continued injection of waste does not increase r_R but, as shown in Figure 2b, the waste continues to expand its contact with the floor of the aquifer. (If the waste is less dense than the native water, the picture must, of course, be inverted; the contact between waste and aquifer floor reaches a maximum for a given injection rate, and the waste-roof contact continues to expand.)

At Louisiana State University we have been trying to write a computer program to enable us to put numbers on this process. We have been verifying our computer program with a laboratory-size aquifer that we call a "miniaquifer." It is simply a slab of homemade sandstone consisting of blasting sand and epoxy in which we have installed a miniature well field together with pumps, sensing devices and recorders. Figure 3 is an overview of the miniaquifer. Figures 4a and 4b are photographs of models that we have carved out of polyurethane based on actual measurements made on the mini-

Fig. 3. Photograph of the miniaquifer with Professors Kazmann and Whitehead in background.

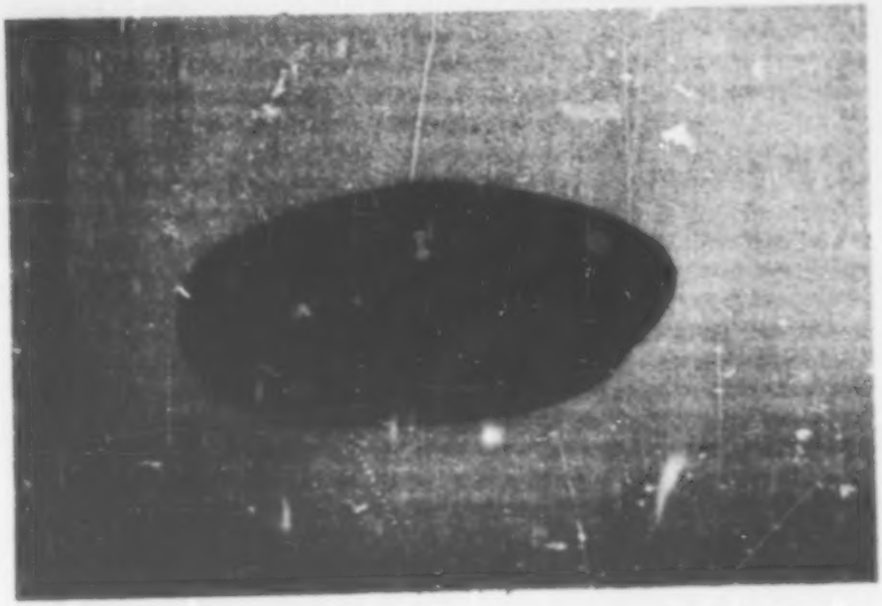

Fig. 4a. Photograph of a polyurethane model showing how a dense waste spreads out from an injection well (white map-tack) in a horizontal aquifer. The model was carved on the basis of the traces of waste front on the roof and floor of the miniaquifer after injection of a volume, V, of waste. The traces of the waste, if viewed from directly above, are circles. $\Delta\rho = 0.43$

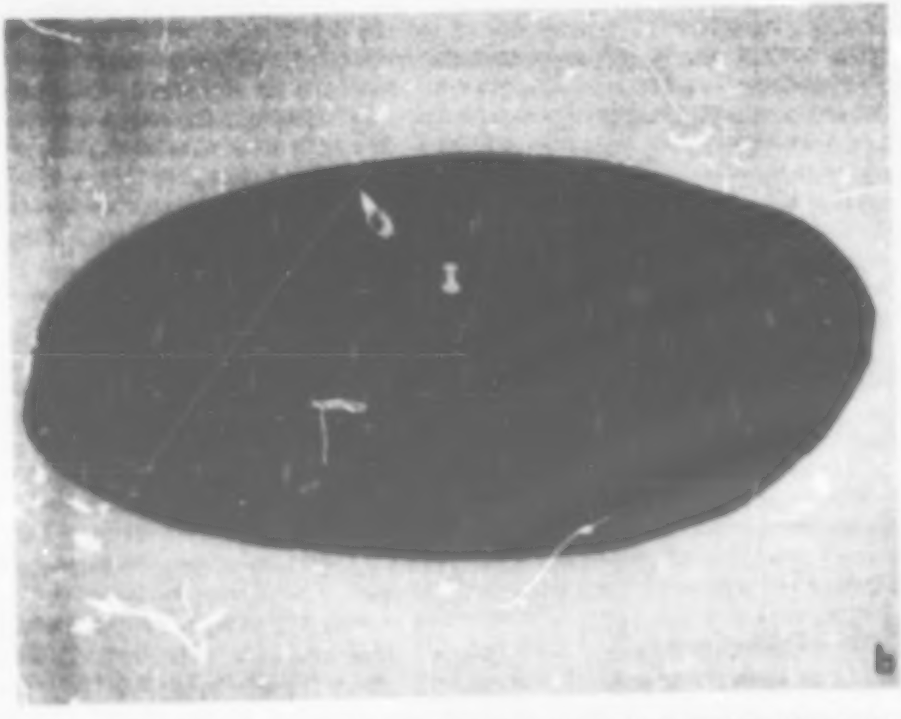

Fig. 4b. Appearance of waste after a volume 3 V has been injected. Note that most of the waste has descended to the floor of the aquifer. The traces of the waste, if viewed from directly above, are circles. $\Delta\rho = 0.43$

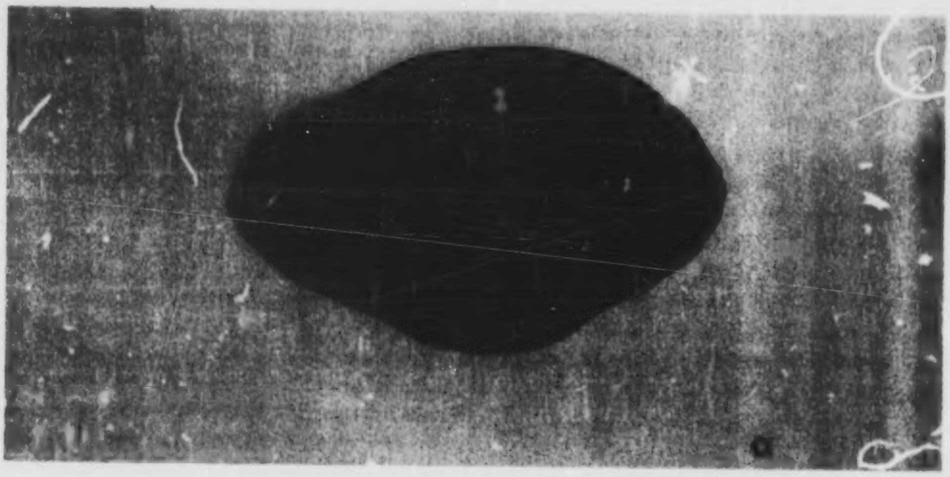

Fig. 5a. Photograph of a polyurethane model showing how a dense waste spreads out from an injection well (white map-tack) in an aquifer that dips toward the camera at an angle of 15°. The model was carved on the basis of the traces of the waste front on the roof and floor of the mini-aquifer after injection of volume, V, of waste (same volume as Figure 4a). The traces of the waste, if viewed from directly above, are not circles, but the downdip radii are much larger than the radii updip. $\Delta\rho = 0.43$

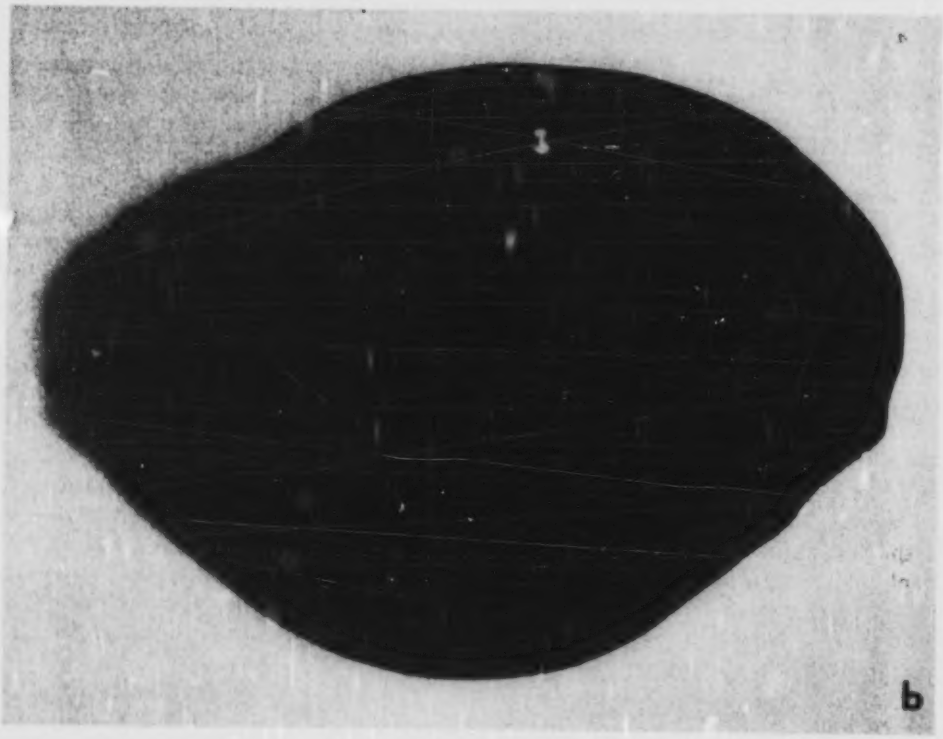

Fig. 5b. Appearance of waste after a volume 3 V has been injected. The traces of the waste, if viewed from directly above, are not circular, but are distorted with most of the waste moving both downdip and to the floor of the aquifer. $\Delta\rho = 0.43$

aquifer. Figures 4a and 4b show how the waste tends to flow to the floor of the aquifer, the r_F keeps expanding while r_R remains about the same.

What is the significance of all this when waste monitoring is involved? Simply this: under the circumstances pictured the monitor well must extend to the floor of the aquifer and must be screened close to the floor if the movement of waste is to be detected. If the well is not placed at the correct distance (depending on density difference, porosity, rate of injection and other factors), and screened in the right place, the waste may not be detected at all by the monitoring system. Moreover, the computation for distance (or time) made possible by Equation 1 is totally useless.

On the other hand, the escape of a dense waste to overlying aquifers at a distance from the injection well reasonably greater than the maximum radius of the waste-roof contact is unlikely. Native salt water may escape, but the waste will probably not; it will continue to spread along the base of the aquifer.

If the complexity of the hydrogeology of the target aquifer is increased because the aquifer possesses dip, the proper placement of monitor wells becomes a real achievement. Based on our experimental work on miniaquifers, for any specified dip angle, density difference and injection rate (not to mention porosity, thickness, and permeability), the waste will move updip for some maximum distance and then the waste front will retreat toward the injection well. Meantime the dense waste has moved downdip and has spread out on the floor of the aquifer. Figures 5a and 5b are photographs of polyurethane models of the slug of waste in a dipping aquifer. The models were made on the basis of observed frontal positions in the miniaquifer during an experimental run.

If any conclusion is to be drawn, it is that monitor wells should not be placed directly updip from the waste injection well when the density of the waste is greater than the density of the native water. Another conclusion might be that it is possible to place monitor wells near the injection well in such locations that no trace of the injected waste will be noted, if the monitoring is to be believed.

Pre-existing ground-water flow in the receiving aquifer will also have an effect on the positioning of monitor wells. Figure 6 is a schematic diagram showing the successive approximate positions of a waste front in a horizontal aquifer together with the cross sections of the waste stream. It should be noted that the word "approximate" is used to modify the word "position." This word is intended to warn the reader that as a waste front moves in an aquifer, miscibly displacing the native water, a "mixed zone" is formed due to convective dispersion (and to a lesser extent, diffusion) in which the proportion of waste ranges from 100 percent to zero. The further the movement of the waste front, the larger the mixed zone becomes. Of course, these remarks are applicable to all of the preceding examples; they were not introduced immediately to keep the analysis from becoming prematurely complicated.

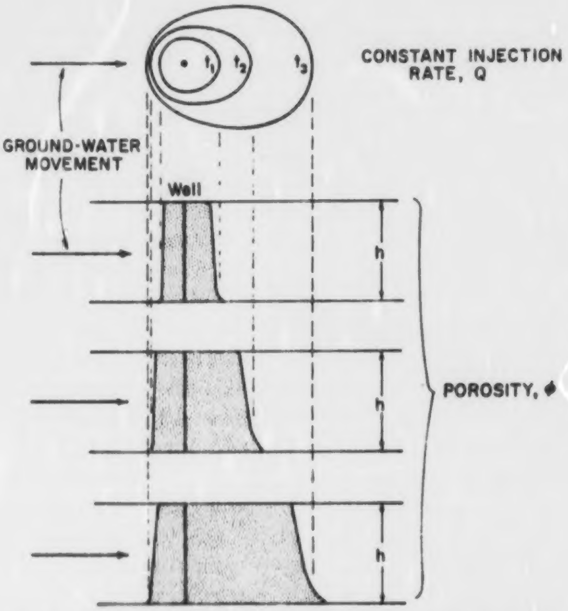

Fig. 6. Successive average positions of the waste front at the ends of different periods of injection (t_1, t_2, t_3). Diagram shows the effect of pre-existing ground-water movement on the shape of the injected volume of waste.

Should the aquifer possess dip and the ground water be in motion, matters become even more complicated; the proper placement of wells for monitoring purposes probably should not be accomplished solely on the basis of the hydrogeological survey prior to the drilling of injection wells. Some of the wells should be installed after a year or two of observations in the initial monitor wells.

The work at Louisiana State University has already resulted in computational procedures that enable the engineer to determine the position of the waste front in a horizontal aquifer or in a horizontal aquifer in which ground-water movement is already in progress. We are still working on the problem of frontal position in a dipping aquifer with the various parameters of ground-water movement, density difference and viscosity difference—assuming miscible displacement.

FIELD APPLICATIONS

The preceding paragraphs bring into focus the necessity of studying the regional hydrogeology as well as the local geology of the target aquifer. Some of the implications of regional hydrogeology have been outlined by Bergstrom (1968) and Bond (1972) but these have dealt with the deep, consolidated aquifers that underlie the State of Illinois. Freeze (1972, p. 128) briefly discussed regional hydrogeology and tentatively decided that as between sanitary landfill and deep well injection, the landfill was a safe and reliable method of disposing of solid wastes (despite the movement of liquid leachate into underlying aquifers) whereas "the injection of liquid wastes into deep geologic formations . . . leads to irreversible subsurface pollution." He did not say, however, whether the existing fluid in the target aquifer could not also be considered "irreversibly polluted."

In the time scale that we have used to evaluate containment, the most satisfactory aquifer is one that possesses dip, is permeable and porous, and the density difference between the native water and the injected waste is not less than 0.02 gm/cc and is, preferably, greater than that, the injected waste possessing the higher density. The miscibility of the fluids is assumed and the assumption made that the viscosity of the injected fluid is equal to or greater than that of the native fluid. The principal requirement is that there be a substantial distance between the point of waste injection and the nearest downdip fault—a distance great enough to require a computed travel time of 50 years or more. For a waste-injection rate of 700 gpm (2.7 m^3/min), an aquifer with an effective porosity of 20 percent, a permeability of 200 gpd/ft^2 (9.4×10^{-3} cm/sec), thickness of 100 ft (30 m), a dip of 40 ft/mile (.0075), and a density difference between the native and injected fluids of 0.10 gm/cc, the minimum distance between the injection well and boundary should be at least 2.5 miles (4 km). We might assume that after the waste front reached the boundary the waste would be "ponded" and would spread laterally along the boundary as the depth of the waste increased, meantime forcing the native water updip and slowly increasing the discharge to the subsea outcrop, which might be several tens of miles away. The waste would be in permanent storage, barring catastrophic geologic changes, at least for a period several times longer than the recorded history of mankind. Since the waste would be moving primarily along the floor of the salaquifer, there would be little chance of upward movement into the biosphere.

CONCLUSIONS

The injection of wastes into deep aquifers that are presently filled with saline water is a technically feasible method of long-term, essentially permanent, removal of wastes from the surface environment. Accepted procedures now in use for the construction of waste injection wells have proven to be satisfactory. The "management" of these wastes has not yet been achieved—the attitude has been, "out of sight, out of mind."

Future waste injection projects should be based on adequate knowledge of the regional geology of the target aquifer; thickness, dip, faults that obstruct regional flow, and the density or density distribution of the native fluid in addition to such parameters as porosity, permeability and storativity. It is highly probable that permanent containment of wastes for periods of time that may be measured in tens of thousands of years will prove feasible. For a waste fluid that is denser than the native fluid the period of containment will depend on the usable volume of pore space downdip from the injection well field to the boundary, be it a fault, a permeability pinchout, or the synclinal axis of the salaquifer.

It may not be much of an exaggeration to say that if the density of the waste fluid is greater than that of the aquifer fluid and the aquifer is not horizontal, the safety of the project is almost certain and the monitoring requirements will be minimal. If the injected fluid is lighter than the native fluid, no parallel statement can be made as to the safety or life of the project, but a system of monitor wells can be devised so that the waste can be tracked and managed—measures can be taken to prevent the waste from reaching the biosphere. Who should bear the cost of such corrective procedures, which might not be needed for decades or centuries, is not a topic here.

Regardless of the ratio of density between the injected and native fluids, monitoring wells will be needed to determine the long-term interactions between the waste, the aquifer fluids and the materials of the aquifer and the confining beds. Osmotic effects cannot be neglected, as they may lead to unanticipated increases in the pressure within the target aquifer and thus increase costs of waste disposal. Thus monitoring of the pressures within the salaquifer will also be required.

Although much remains to be accomplished, computational procedures to yield the required information for the proper placement of wells for monitoring have been developed for specific hydrogeologic circumstances—when there is little or no pre-existing ground-water flow and the aquifer dip is small or negligible, and when the aquifer is horizontal and there is ground-water flow. The computational procedure has been applied to the prediction of results of injection into a small, laboratory size, artificially consolidated, sandstone aquifer. The equations, and computational procedure for solving them by a stepwise procedure, have been substantially validated by visual observation of the movement of fluid in the laboratory aquifer.

The equations and the procedure have been applied to typical hydrologic situations in the field, using parameters that are typical of aquifers that might be used to contain waste materials. Based on this information the distances and directions of wells for monitoring the movement and quality of waste have been computed.

Additional work in the field of miscible displacement is needed to provide a sound basis for the engineering design of monitoring facilities for management of wastes that have been injected into salaquifers. Present computational procedures must be improved and their range of applicability extended. Verification of the computational results by applying them to miniaquifers in the laboratory should, logically, precede field testing.

Note: Printouts of the computer procedures to determine the frontal positions in a horizontal aquifer with or without pre-existing ground-water movement are available upon request to the Louisiana Water Resources Research Institute.

ACKNOWLEDGMENTS

Much of the experimental and computational work referred to in this paper has been performed by graduate and undergraduate students of the Departments of Civil and Petroleum Engineering at Louisiana State University under the direction of the writer and Professor O. K. Kimbler of the Department of Petroleum Engineering (1970, 1974). Special mention should be made of the experimental and computational efforts of Omar Esmail (1967), Anil Kumar (1970), Thomas Painter (1971), Walid Esmail (1973), and Walter R. Whitehead (1974). Many of the computations, and the experiments that were photographed, were performed by Dr. Whitehead while he was obtaining his Ph.D. degree at Louisiana State University, and the writer is most grateful for his assistance. The various phases of the work were funded under grants administered by the Louisiana Water Resources Research Institute and funded by the USDI Office of Water Resources Research under P.L. 88-379. The theoretical and experimental studies have been accomplished under projects A-002-LA, A-011-LA, A-022-LA, A-027-LA, and A-034-LA.

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DISCUSSION

The following questions were answered by Raphael Kazmann after delivering his talk entitled "Waste Surveillance in Subsurface Disposal Projects."

Q. by C. A. Pascale. *What was the difference in density between the 2 fluids used in your models?*
A. 0.45 gr/cubic cm.

Q. by Dan W. Bench. *What is the importance of the injection pressure and the possibility of hydraulic fracturing?*
A. The maximum injection pressure, as indicated in the paper, should not be permitted to exceed 80 percent of the fracturing pressure, defined as one p.s.i. per foot of depth. An aquifer 1000 feet deep would have a frac-pressure of 1000 p.s.i. and the maximum pressure in the aquifer due to injection should be kept below 800 p.s.i.

Q. by Kent Ballentine. *On a policy basis, does it seem reasonable to discharge a noxious fluid into an aquifer which has sufficient flow to distort the fluid front profile? Is this containment?*
A. Yes, to both questions. With an appropriate and adequate density difference and a sufficient distance to the point of discharge the system can be made perfectly safe for as long a period as might be desired.

Q. by K. Childs. *Deep wells are really a method of waste storage, not "disposal." What is the long-term effect of storing large volumes of undesirable liquid, frequently under high pressure, in the ground? Consider the problem in Colorado of recent earthquakes.*
A. This is really two questions in one. The choice of very deep, fractured igneous rocks in which the fluid pressure was relatively low was not a good one. The increase in pressure due to injection reduced the grain-to-grain frictional resistance to lateral or vertical stress and facilitated stress-relieving rock movements that were manifested as earthquakes.

Storage of wastes in deep sandstones or unconsolidated granular material should just increase the pressure and either additionally compress the native fluid or force it to its outcrop more rapidly, depending on whether or not ground-water movement was occurring prior to injection. The geochemical hydrodynamics (produced by osmotic forces) were not covered in the talk, but the pressure sensing monitor wells would show an unanticipated, uncalculated increase in pressure which would serve to alert the waste managers that some pressure relief operations (by removing native fluid) might be in order.

Q. by H. R. Sweet. *How do you take into account vertical-horizontal permeability differences?*
A. At this time we do not even know how to determine such differences by means of field tests. Under such circumstances it would be essential that the injected waste be denser than the native water.

Q. by S. K. Tyagi. *Waste disposal though recommended higher in density will contaminate the aquifer by virtue of the fact that it comes in contact with the aquifer. Please comment.*
A. Chemical interaction between waste and aquifer material was not covered. However, the aquifer should be studied (samples of fluid, material, confining beds, etc.) for chemical reactions between waste and aquifer components. The waste will, if denser than native water, spread downdip along the floor of the receiving aquifer.

Q. by R. C. Scott. *In reference to the last slide (Figure 6), should not the interface tilt be greater on the stabilized upgradient front than on the mobile downgradient front, as long as that front is moving?*
A. The upgradient interface will be closer to the vertical than the downgradient interface.

Hydrocarbon Dispersion in Ground Water: Significance and Characteristics[a]

by John O. Osgood[b]

ABSTRACT

Ground-water contamination resulting from hydrocarbon spills is a significant problem which has received little attention. Over two hundred spills to the ground have been investigated during the last two and a half years by the Ground Water Section of the Pennsylvania Department of Environmental Resources. Explosions, injuries, damaged water supplies and other serious consequences have forced the recognition that these cases are important. Since Federal regulations are unsatisfactory in preventing spills to the ground, it is clearly the responsibility of the State to develop meaningful controls.

Hydrocarbon dispersion is essentially a shallow ground-water problem. The hydrogeologic characteristics at the spill site are critical in determining dispersion once the hydrocarbon has reached the water table. The hydrocarbon is largely contained on top of the water table. In unconsolidated deposits or in fill material, the shallow ground-water flow system and the direction of hydrocarbon dispersion will coincide. In sedimentary rocks the orientation of the rock becomes critical. When the dip is shallow enough to contain the water table, dispersion may either coincide with the major flow direction or may diverge from it where facies changes or significant changes in packing are encountered. Dispersion will parallel the strike of the rock in more steeply dipping rocks rather than the major ground-water flow direction. Lateral movement will be controlled by jointing and fracturing. Solution channels and fractures exert the major controlling influence on heavily cemented soluble limestones. In tightly cemented clastics, crystalline rocks and less soluble carbonates, contaminant flows on top of the water table in fractures. Hydrocarbons may be imprisoned where solution channels and fractures do not intercept other openings within the water-table plane.

Recovery programs for most hydrocarbon spills are complex. Larger cases receive the greatest attention; however, smaller ones are actually more significant since they are more common. Recovery costs are expensive and complete removal is extremely time-consuming. Better maintenance and emergency response plans must be developed, even by small users. Federal and State governments must recognize the problem as being serious and must develop revolving product recovery funds to be used in ground-water cases. Lastly, ground-water spills must be handled by ground-water specialists. Experimentation by those who lack the proper qualifications can prove very costly.

INTRODUCTION

We have begun as a nation to recognize the harmful effects of hydrocarbons on the environment. Effective regulations have been established to protect our streams, lakes, ocean waters, and air from contamination. However, the same degree of concern shown these areas is lacking when hydrocarbon spills to ground water are considered. The Federal Government took the lead in oil pollution prevention when the Federal Water Pollution Control Act of 1972 was passed. This legislation excluded spills to ground water from consideration. Even when subsequent amendments were added to strengthen controls on oil spills, prevention of ground-water pollution was still excluded from its scope. Part 112, for example, was added in 1973 to establish Spill Prevention Control and Countermeasure (SPCC) Plans. SPCC Plans outline the measures required of oil handlers and processors to develop prevention and recovery activities which can be initiated rapidly if a spill occurs. It is interesting to note that petroleum facilities with a total subsurface storage capacity of less than 42,000 gallons are not required to develop these plans. This amount of gasoline is enough to pollute 6.7 trillion gallons of ground water beyond the threshold of taste. That is equivalent to 40 years of

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Philadelphia, Pennsylvania's present water-supply needs. In contrast, a facility having a single, above ground, storage container with a capacity exceeding 660 gallons is required to develop a plan. In addition, regulations requiring SPCC Plans apply only when facilities "due to their location, could reasonably be expected to discharge oil in harmful quantities . . . into or upon the navigable waters of the United States or adjoining shore lines" (EPA, 1973). If the oil can be contained by the hydrogeologic system, no plan is needed. No attention is paid to the near permanent damage which may be done to the subsurface environment. It is obvious that the Federal Government specifically excluded the protection of ground water from their oil pollution prevention laws.

In the absence of Federal guidelines, it is the responsibility of each State to establish its own ground-water prevention and emergency response program. Pennsylvania is meeting this challenge. The following discussion outlines some of its conclusions.

SIGNIFICANCE

During the past 2½ years, geologists from the Ground Water Section of the Pennsylvania Department of Environmental Resources have investigated over 200 hydrocarbon spills as part of their normal prevention-abatement program activities. One point above all others has made itself clear—that spills to the ground water are significant and dangerous. In that time, more than 8 homes were destroyed when fumes entered the houses, concentrated to explosive levels and ignited. At least 17 persons were injured in these explosions, 3 seriously. In addition, 115 homes were abandoned or adversely affected by gasoline fumes. Many were uninhabitable for extended periods while others were permanently abandoned. Fourteen public-water supplies were threatened or polluted affecting the water needs of over 800,000 persons. The water quality of 104 wells was seriously damaged when they became contaminated by petroleum pollutants. The individuals affected were required to obtain alternate water supplies by redrilling their existing wells, by drilling new wells, by joining public-water systems, or by carrying water until their supply became useable once again. This was usually accomplished with an exasperating amount of personal hardship.

Solutions to cases where ground water has been polluted by hydrocarbon spills are almost always complex and time consuming. Many times the damage can be considered permanent since no practical recovery within a reasonable time period is possible. It is estimated that in the Commonwealth of Pennsylvania spills or leaks of petroleum products are the third leading cause of ground-water pollution. Although the frequency of hydrocarbon spills varies from State to State, the severity of the problem and the potential dangers derived from them makes the experiences learned in Pennsylvania typical. The situation is serious.

Almost every case which has come to the attention of the Department resulted from a pollution complaint. This is true in spite of a very strong State regulation which requires the individuals responsible for a spill or leak to notify the Department immediately after it is discovered. Two factors account for the situation. The problem is aggravated by the almost universal attitude faced by those of us involved in ground-water protection—the lack of insight shown by people who do not understand what they cannot see but who, by the very nature of their work, should. Further, petroleum handlers commonly underestimate the impact of a "small" spill on the subsurface environment. Compared to the large volumes sold, sloppy handling of gasoline or the slow leak of 200 gallons at a service station is either overlooked as being unimportant or passes unnoticed. Losses of 10,000 to 15,000 gallons of various liquid petroleum derivatives from buried pipelines can go unrecognized until some sign of the leak is spotted at the surface. Six thousand gallons of gasoline or fuel oil spilled from an overturned tank truck and washed into the soil along the roadway is considered a safe way of getting rid of the problem. One such case in central Pennsylvania resulted in the partial closing of an interstate highway, intermittent explosions for several days from a nearby spring, the destruction of aquatic life for over one mile downstream of the ground-water discharge point, the closing of a public water supply located approximately 2 miles downstream for one day, the partial abandonment of a nearby motel as a result of fumes, and in extensive fines and recovery costs for the company transporting the material. At the time of the accident, all wreckage was cleaned up and the spill product was allowed to soak into the ground. The fire department, the driver, and the owners of the trucking company returned home unaware that the most significant impact from the accident was yet to come.

Many similar examples can be cited. Volumes lost in the cases investigated were as little as 10 gallons to as much as 300,000-400,000. Approximately 50 gallons were lost in one case when a slow

Table 1. Distribution of Cases Involving Hydrocarbon Spills Handled by the Ground Water Section Since 1971

Type Causes	*Percent*
Service Station Leaks	51
Private Sources	18
Pipeline Breaks	9
Industrial Storage Tanks	9
Bulk, Storage Areas	7
Transportation Spills	4
Unknown	2

leaking valve on a tank truck dripped fuel oil to the ground. The truck was being used to refuel vehicles at a construction site and was parked in a driveway for only 2 afternoons. Two private wells were made unuseable for several months as a result. Another case developed when crude oil was discovered in a newly installed well. The investigation showed that a pipeline break in 1953 had spilled a tremendous volume of crude oil which was never cleaned up. It was still there 20 years later.

The distribution of cases which the Ground Water Section has responded to since 1971 (Table 1) indicates that buried gasoline tanks at service stations have been the most common source of leaks investigated. There are over 11,000 service stations in Pennsylvania and approximately 2,300 subsurface gasoline tanks are installed in the State each year. The number of known leakers are relatively small when compared to the total of newly installed tanks. However, many of the new tanks reflect new service station installations and increased volume capacities through tank replacements. The majority of those remaining are undoubtedly replaced as a result of leaking tanks and are never reported.

The first major push to force storage tanks underground occurred as a precaution during the Second World War. As a result, large numbers of buried tanks are now approaching the end of their tank life. Additional problems can be expected from the abandonment of service stations and their conversion to other uses as a result of the recent "gasoline crisis." Stations placed back into service after being out of use for extended periods may especially be prone to leaks. During this period, management frequently changes hands, the facility can be placed back into service with inadequate preparation and the long period of disuse can stimulate corrosion if the tanks remain empty.

The common service station problem is identified when neighbors taste or smell gasoline in their water or recognize its odor in their homes. Volumes lost are generally in the 200 to 600 gallon range; however, losses up to 14,000 gallons have been investigated. Service station cases are usually quite significant since they are frequently located in built-up areas where serious problems may develop. Rapid recovery actions are required to contain the lost product. This is almost always hampered by the fact that the station manager is unprepared for this type of emergency.

When the Department is eventually notified, a Regional Geologist is sent immediately to investigate. This is true for any petroleum spill regardless of its source and a response time of 2-3 hours is attempted for any spill in the State. He makes an assessment of the situation and directs the initial recovery operations. If he feels that the case can be handled quickly, he will direct all recovery operations himself. The responsible party is expected to obtain all equipment and man-power required. If the case is more involved, the Regional Geologist will require the responsible party to hire a Ground Water Specialist to work under the Regional Geologist's direction. The specialist will identify the extent of contamination, develop a recovery program, and conduct recovery operations. The responsible party is required to finance these activities until the problem is abated to the Department's satisfaction. If no responsible party is identified or if a stronger legal case is necessary, recovery actions are made more difficult. Task forces have been voluntarily established in some cases by all operators who may be potentially responsible. Each member contributes an equal share to the recovery program When a case is considered an emergency situation, the State will supply funds from a revolving account established by the Pennsylvania Clean Streams Act. All expenditures are recovered from the responsible party once the source is identified. Very minor cases where recovery is for all practicable purposes impossible, are monitored until the problem subsides. This method of operation has proven to be very effective.

Heating oil leaking from buried and surface storage tanks at private residences is another important cause of contamination. Since these tanks are not monitored during use, it is difficult to assess the amounts lost. Tank sizes are usually small; however, small leaks over long periods of time can account for considerable amounts of product lost. Estimates are usually from 100 to 300 gallons; however, in at least one case approximately 4,000 gallons of fuel oil was lost.

Pipeline breaks supply some of the largest volumes lost to the ground water. As such, they usually get a great deal of attention. One break, occurring in northeastern Pennsylvania, spilled high octane gasoline into the well field of a public water supply. Over 130,000 gallons were lost in the soluble limestone terrain. Forty-three recovery wells were drilled and through quick action most of the product was retained at the site. Though the ground-water quality of the well field was ruined, the existing wells served to contain the spill and were the first step in recovery operations.

Storage tanks at industrial factories, power plants, transportation establishments, and other similar facilities are also places where leaks of petroleum are common. Many cases are similar to service station problems since the same size tanks are usually involved. Losses of up to 8,000 gallons have been investigated. Other cases connected with industrial activities result when poor handling and disposal techniques enable petroleum materials to be spilled onto the ground during manufacturing and processing. These cases are usually quite advanced before the problem is recognized. Small amounts of waste spilled over long periods of time disperse widely. Recovery is difficult, costly, and usually meets with a great deal of resistance on the part of responsible individuals who must pay recovery costs.

Bulk storage areas are another major source of hydrocarbon spills. Cases have resulted from leaking underground lines within the safety dike areas, from draining operations involving condensate removal, from ruptured tanks, and from faulty fittings. The amount lost is quite variable and has the potential to be tremendous. The majority of safety containment impoundments surrounding bulk storage areas are not impermeable. Many even contain outcrops which serve as perfect direct avenues of escape for the spilled product (Figure 1). Two thousand four hundred thirty-six gallons of gasoline were lost in one case when a large tank overtopped while it was being filled. The gasoline escaped so fast through the highly soluble limestone underlying the site, that no product could be recovered.

Accidents occurring during transportation of product offer special problems. The prime concern at the accident site is the prevention of explosions and fires. This is usually done by washing the petroleum into the soil as fast as possible. The major danger, however, is that the problem is just being transferred. Though it is recognized that the safety of human life must be the first consideration, many excellent sorbent materials are available. They can be spread on the migrating gasoline or oil and removed in most cases. This will reduce fumes and facilitate product recovery. Fire departments and petroleum handlers should give thought to retaining spilled materials before they cause major environmental damage. The volumes of petroleum lost varies from only a few gallons in an automobile accident to several thousand gallons in railroad derailments. Thirty-five thousand gallons of oil were spilled in one railroad derailment in northwestern Pennsylvania alone. Tank truck accidents are also a cause of ground-water pollution. The case previously cited is an excellent example.

Fig. 1. Outcrops located in safety containment impoundments at bulk storage areas offer an excellent avenue for the escape of spilled gasoline.

The largest case in the State occurred in 1970 when gasoline was identified in a newly drilled well. The source is unknown to this day in spite of a substantial effort to locate it. Recovery activities were conducted by a task force of all petroleum handlers in the area under the Department's direction. Three bulk storage areas and two major pipelines are located within a quarter square mile of the site. Over 270,000 gallons of raw gasoline have been recovered to date and operations are still continuing.

Spills and leaks of petroleum products are frequent enough and serious enough to merit special attention. We are talking about more than just dirty water. The well-being and indeed the very lives of the citizens of this nation are endangered when proper respect is not given to the problem. The responsibility is clear. It is up to each State to examine its regulations and integrate the dispersed regulative authorities into one effective response team. This must be done in order to protect the health and welfare of its citizens as well as the water resources of its State.

CHARACTERISTICS

Ground-water contamination resulting from hydrocarbon spills is essentially a shallow-water problem. This is due to the relative insolubility of hydrocarbons in water. The water table acts as an impenetrable barrier to the downward migration of the spilled hydrocarbons. As a result, the dispersion of hydrocarbons is basically limited to the curviplanar surface of the water table. Since the water table generally reflects topography, relating the ground-water flow system to topography usually serves as a good guide. This generalization can especially be applied when the flow of soluble contaminants is being traced. Soluble contaminants are able to move through the ground-water system in a true 3-dimensional manner. Hydrocarbons, however, must flow in the direction of least resistance on top of the water table. Contaminant transport under static conditions is, therefore, controlled by the ability of the hydrocarbons to circumvent obstructions within this plane of flow. Thus, 2 major hydrogeologic factors act in conjunction to control hydrocarbon dispersion, barriers to planar flow which retard flow under static conditions and water-table fluctuations which permit hydrocarbons to flow under or over these obstacles.

Generally, the characteristics of the base materials at the spill site are critical, since they control the barrier properties which obstruct dispersion. Rates of supply and volumes lost, however, have a greater influence on the actual dispersion characteristics than do the base materials when fill and unconsolidated sediments are involved. Spilled hydrocarbons begin to saturate the soil as soon as they are released. Relatively large volumes lost over short periods of time will develop mounds. The mounds are supported by the relative porosity, permeability, adsorption, and pellicular characteristics of the base materials which resist downward flow. Dispersion occurs as the product moves out on the water table from the "leaking" mound. In fill or in unconsolidated sediments, flow is largely unconfined. As a result, the major flow direction of the hydrocarbons will coincide with the major flow direction of the shallow ground-water system. Controls on the flow of hydrocarbons are minimal and dispersion is commonly rapid. A wider area is usually affected than when consolidated materials are involved. Recovery operations are generally more difficult especially when quick action is not taken. The hydrocarbons disperse to a thin layer which usually requires extensive trenching for shallow water tables and wells for deeper ones. Pumping the wells recovers little product and considerable water which increases disposal problems.

Many of these dispersion characteristics change in consolidated materials. Contaminated flow is controlled very heavily by geologic factors. In sedimentary rocks, the orientation of the rock and the primary depositional characteristics of the unit are as critical as porosity and permeability. Whether the principal influence on ground-water flow will be the sedimentary characteristics of the rock or its fracture properties is to a large degree controlled by the extent of cementation and packing. Fracturing becomes more important in controlling ground-water flow characteristics as the rock becomes denser and the hydrocarbon contaminant will flow into fractures where they intercept the water table. In poorly cemented to moderately cemented sedimentary rocks, the orientation and depositional characteristics of the unit are most important. When the dip is shallow, facies changes and sorting and packing characteristics control dispersion and dispersion rates. Under these circumstances, the water table is essentially within a single geologic unit and lateral changes in texture act to impede contaminant flow. The hydrocarbons flow at an angle to the local ground-water flow system as it moves around these obstacles (Figure 2). In more steeply dipping rock units, the dominant flow direction of the hydrocarbons is parallel to the strike, downslope, rather than down the dominant local hydraulic gradient (Figure 3). Deviations from the strike direction are accomplished through a side-stepping action controlled by jointing and fracturing. The normal tendency of the hydrocarbons to move in the major ground-water flow direction is offset by its inability to penetrate successive bedding units in the direction of dip. Each unit has a different set of

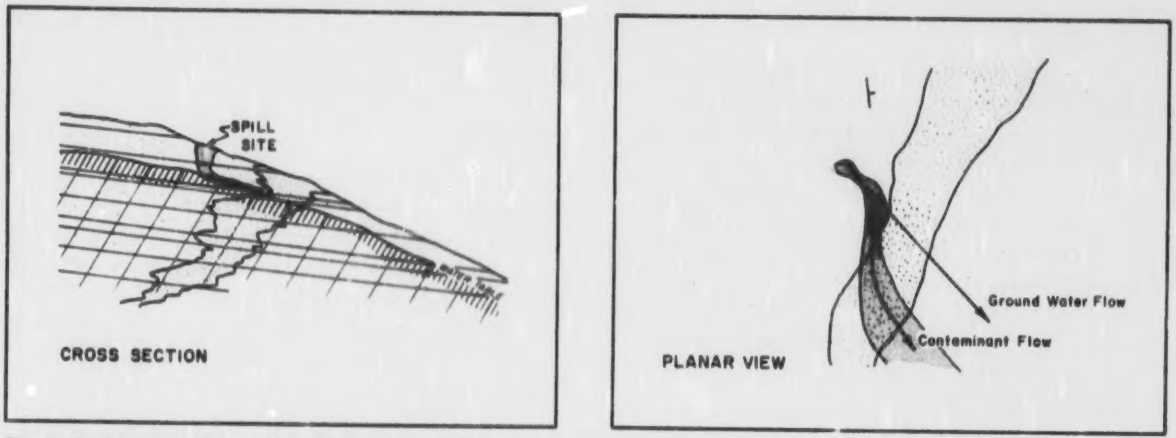

Fig. 2. Hydrocarbon flow is diverted by facies changes and packing changes in shallow dipping clastic sedimentary units.

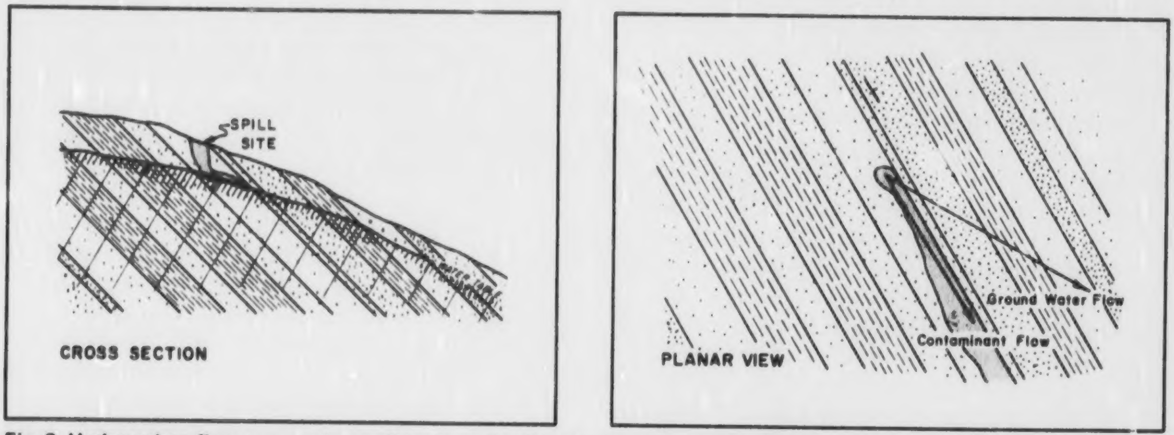

Fig. 3. Hydrocarbon flow commonly parallels the strike direction in more steeply dipping sedimentary rock units.

weathering, textural, and packing characteristics which act to inhibit planar flow. This feature acts to channelize the hydrocarbons which may facilitate recovery operations once the particular bedding channel has been discovered. Gasoline was first discovered flowing from a spring in one case investigated. The source was subsequently discovered to be a leaking pipe buried in a bulk storage area approximately ¼ mile away. The leak was almost directly on strike. Wells were drilled along major fracture traces to facilitate recovery operations, and discharge locations downgradient from the leak site were monitored. No deviation from the strike direction occurred. This is still true 2½ years later. Small amounts of gasoline are still flowing and still being collected from the spring (Figure 4).

In carbonate rocks, unit orientation, as discussed before, solution openings and fractures are the 3 most important factors controlling dispersion. The network of solution openings and fractures form a complex flow system. In some cases, these systems hold the hydrocarbons for long periods of time while, in others, the product

Fig. 4. Gasoline is collected in impoundments as it flows from a spring in the foreground. A leaking buried line in the bulk storage area caused the problem.

maneuvers through a circuitous route. Recovery operations are extremely complex and usually require an extensive drilling program.

Fractures are extremely important when tracing dispersion directions in crystalline rocks, tightly cemented clastic rocks, and in poorly soluble carbonates. Hydrocarbons flow on top of the water table in fractures where they may be imprisoned when they do not intercept other openings within the water-table plane. Fracture trace analysis, using airphoto interpretation, is the best method of locating major fractures which could be transporting the spilled product. Well-developed local fracturing systems can carry the product quickly over large areas through rather random paths.

Hydrocarbon dispersion has been treated as a 2-dimensional system up to now; however, the third dimension is supplied by fluctuations of the water table. Activities which take place within the capillary fringe zone may also be important in supplying vertical mobility. These activities enable hydrocarbons to migrate over and under obstacles which would otherwise retard flow. As a result, dispersion is able to advance beyond the point it would have been capable of under static conditions.

Water-table fluctuations permit considerable dispersion in carbonate terrain. Spilled product can migrate through the soil until it enters a solution channel where it is impounded on top of the water table. No indication of a problem may have developed up to this point. A rising water table can then lift the hydrocarbons over an obstacle to higher solution channels where dispersion will continue. Some product is left behind in pockets when the water table drops. Later shifts may advance the hydrocarbon to wells where the contamination may be noticed for the first time. The pipeline break, referred to earlier, which occurred in central Pennsylvania in 1953, spilled 40 to 50,000 gallons of crude oil into the ground. The area was farm land and a private well near the spill was contaminated. The well was heavily pumped for 3 months and a settlement finally was made with the owner of the well. In the mid 60's, a severe drought hit the area. The water table dropped and wells for several miles began showing hydrocarbon contamination. The problem cleared when the water table returned to its original level. To this day, pockets of the raw product are found when new wells are drilled and places where crops will not grow are common. In a few rare cases, evidence seems to indicate that another type of hydrologic pumping may occur. It may be possible for the product to move upgrade in poorly consolidated units perhaps by a mechanism similar to soil creep in reverse. The buoyant character of the hydrocarbon is an upward force in the vertical plane opposed to gravity. Regional ground-water fluctuations parallel the inclined plane of the water table. Frequent minor fluctuations may pump the product upslope lifting it vertically and settling it back at higher elevations when the water table drops. Another explanation may be that the gasoline undergoes a phase change from a liquid to gaseous state, migrates upgradient, and then changes once again back to a liquid. Research into these possibilities would be most interesting.

Though oil products are generally not found in deeper systems, they will, under certain circumstances, contaminate deeper aquifers. The most common cause results from dewatering of perched aquifers. Complex bypassing of several wells is common and depends upon casing properties. When water supplies become critical during dry periods or when improperly sealed or abandoned wells permit the shallow system to drain, drawdown from active wells will frequently pull hydrocarbons into its cone of depression. Flow towards the well will concentrate the hydrocarbons around the outside of the casing as more is added. In other cases, raw product will be drawn into the well casing where it collects on top of the water column in the well. Regardless, trace amounts may be carried down to the pump where they are transferred to the storage tank. Hydrocarbon build-up can occur in the tank causing persistent taste and odor problems. Problems of this type give the appearance of deeper aquifer contamination and many times will continue even after the well is redrilled and recased.

One of the greatest dangers from hydrocarbon spills is the problem of fume build-up. Vapors continuously rising from the contaminated water table normally dissipate at the soil surface with little build-up; however, openings such as wells (Gold, Parizek and Giddings, 1970) or basements frequently permit fume concentrations to reach explosive levels. The most critical time for potential explosions is after a heavy rain, which saturates the upper soil zone or during winter when the ground freezes. Fumes cannot dissipate and concentration occurs. Fumes have migrated laterally 100-200 feet under the cap through open pores and fractures into nearby buildings. One such incident occurred recently when the home belonging to a senior citizen in central Pennsylvania blew up. Gasoline fumes reached explosive levels in her basement and ignited. Fortunately, she was not at

Fig. 5. Three successive explosions destroyed this house when gasoline fumes concentrated in its basement. The fumes originated from the contaminated water table under the home.

home at the time. The local fire department responded and extinguished the fire. As several firemen were inside checking for sparks, the house exploded a second time. Sixteen men were hospitalized from that blast (Figures 5 and 6).

Every case involving hydrocarbon spills to ground water seems to be unique. The complexity of these systems is such that hydrocarbon dispersion has the potential of going in any direction. Hydrocarbons may move directly down the major hydraulic gradient; they can be held in suspension at the spill site by pellicular attraction (McKee, Laverty and Hertel, 1972); they may move at an angle to the major hydraulic gradient; or if proper conditions prevail, they may move upgradient. A proper understanding of the hydrogeologic properties in the area of either the spill site or the affected site can eliminate many variables. This is true even if

Fig. 6. Firemen view damage done to the home after explosion. Several firemen were hospitalized as a result of the blast.

they are only generally understood. Prompt effective action can, therefore, be taken in determining the extent of contamination and developing a recovery program. Major case studies involving large volumes of product seem to draw most of the attention, yet smaller ones where losses of 100 to 3,000 gallons occur are equally difficult to handle. Consequences may even be more serious since the initial reaction is to let small spills go farther than large ones before notification or recovery operations are initiated. Since these cases occur much more frequently than larger spills, they are actually more significant.

Equally important are the problems associated with the disposal of waste hydrocarbon products. Improper disposal merely transposes the problem from one place to another. In Pennsylvania, approval must be given by the Ground Water Section before the saturated recovery materials and recovered product can be disposed. Acceptable methods include incineration, bacterial decay, reclamation, land disposal, and reuse. As a result of the serious consequences which can occur, most hydrocarbon spills are considered emergency situations. Special permission from State air pollution authorities is granted in these cases when recovery volumes are small, less than 200 gallons, to incinerate the waste. The material is removed to a safe location and burned in open pit incinerators under supervised conditions. When larger amounts are involved, a separator is constructed and the raw product recovered is sent to a refinery or blended into a pipeline for reuse. Contaminated soil and sorbent materials may be taken to landfills having collection and treatment facilities where they may be spread thinly and mixed with the soil in an area not being used. This method, however, is less efficient in the northeastern climate than in less humid regions. Another disposal method for handling larger amounts of contaminated waste is to transport the materials to approved incinerators. Specific low-temperature incinerators with proper air pollution controls have been selected to accept these wastes. The wastes are fed into the facility at a controlled rate under the direct supervision of the Regional Air Pollution Engineer. This method is preferred over land disposal. Microbial activity was used in one case to effectively remove an estimated 30,000 gallons of gasoline. Injection wells were used to force air, nitrogen and a phosphate buffer into the ground-water system. This effectively accelerated bacterial growth.

Recovery costs for minor spills average approximately $100 per gallon recovered. Approximately $600,000 has already been spent by State and private parties in recovering the 270,000 gallons of gasoline, referred to earlier, in the largest case in the State. These figures significantly support the fact that the best method of handling hydrocarbon spills is to prevent them. Regular maintenance programs are absolutely necessary. They must apply to all buried tanks, especially those in service stations, as well as larger storage and transportation facilities. Hydrostatic pressure tests should be conducted periodically. The test frequencies should concentrate on the first and last quarters of tank life, since these appear to be the most critical periods for breaks. Emergency response plans should be developed for all petroleum users, even small ones. They should be prominently displayed so that all responsible employees can initiate emergency notification procedures when necessary and should include all telephone numbers for emergency equipment, recovery supplies, manpower, notification procedures, and other related information. The problem of service station leaks will undoubtedly increase as tanks are abandoned or placed back into use after long out-of-service periods resulting from the gasoline crisis. All tanks should be removed or filled with concrete if they are to be abandoned and pressure tests should be conducted before tanks are placed back into service.

Diked areas around large bulk storage areas should be free of out-crops and be impermeable to the least viscous material stored. Automatic drains and alarm systems should be installed. Wells should be drilled for each facility to serve the dual roll of monitoring and, when necessary, recovery points. All buried intrastate pipelines should be cathodically protected from electrolysis. This is presently required by Federal regulations for interstate pipelines. Automatic shutoff valves should be located closer together to facilitate prompt pressure testing when it becomes necessary to check a line for leaks. Fire departments should receive instruction concerning the problems of washing spilled product into the ground. They should have sorbent materials as part of their equipment arsenal to recover the majority of product before it escapes from the spill site. All petroleum users should be required to carry insurance policies which protect the environment from contamination. The use of buried heating fuel tanks for private residences should be discouraged, since the average citizen is ill-equipped to monitor the condition of his tank or take steps to recover the product if a leak develops. Federal, State, and municipal governments must recognize these problems as being serious and must develop stronger regulations and revolving funds, which can be used in ground-water cases. Lastly, ground-water spills must be handled by Ground Water Specialists. Experimentation by those who lack the proper qualifications can prove very costly.

CONCLUSION

Hydrocarbon spills and leaks are serious, complex problems. This nation consumes tremendous volumes of petroleum each year and facilities designed to store and transport the products are seemingly everywhere.

Spills and leaks to ground water, regardless of their size are potentially dangerous. Even minor cases cause long-term discomfort for those involved. Quick action is the key to abatement of spills and will result in simpler, less expensive recovery operations. Better maintenance programs are the most effective preventive measures which can be taken. Hydrogeologic characteristics have a major impact in controlling the direction of hydrocarbon dispersion. An understanding of their properties enables the implementation of a rapid emergency response program which should define the extent of contamination and recover the lost product. This paper was meant to present in a general way the findings of the Ground Water Section. It is difficult to assess how large the problem actually is. We feel that in spite of all we have done, we are only tapping the surface.

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DISCUSSION

The following questions were answered by John O. Osgood after delivering his talk entitled "Hydrocarbon Dispersion in Ground Water: Characteristics and Significance."

Q. by K. Childs. *Discuss the feasibility of removing hydrocarbons from the ground-water aquifer, for example by pumping.*

A. Many factors control dispersion. The length of time the product is being spilled, the volume lost, the rate of loss, viscosity of the material, depth of the water table, and the characteristics of the hydrogeologic flow system are some of the major considerations. The amount of product which can be recovered by any system is dependent upon the interrelationships of these factors. Though I may have indicated otherwise when I answered the question originally, the use of wells can be an effective recovery tool. It is not a very efficient method, however. Pumping is the only way to remove hydrocarbons from the ground under deeper ground-water table conditions. The efficiency is greatly increased if large volumes have been lost or if dispersion has not progressed far. In any case, pumping usually results in large amounts of water and relatively small amounts of product. This product must be separated from the water which now becomes another disposal concern. When dispersion has been extensive or when only small amounts of product remain, pumping becomes an expensive activity with limited value. Generally speaking, wells act to collect hydrocarbons which have been carried towards them by the shallow-flow system. The cone of depression does not draw the hydrocarbon to the well in an efficient manner. This is especially true when a static cone of depression has been established. Since hydrocarbon flow is largely isolated to the water table, static conditions enable barriers to retard flow. Much better results seem to be obtained when water-table levels and pumping rates are permitted to fluctuate. In limestones, a critical water table is frequently reached where pumping is especially effective. At other levels, little to no product is recovered. Under shallower ground-water table conditions, trenching is the most favorable recovery technique. Product can be removed by skimming from the top of the water table and sorbent materials can be used. Like wells, the trenches would be situated to intercept the shallow ground-water flow system carrying the contaminant. I suggest anyone interested in recovery techniques, review the publication produced by the American Petroleum Institute identified in the bibliography of my paper. A good discussion of techniques used to recover spilled hydrocarbons is presented.

Q. by K. Childs. *Are your water plume models supported by sample results or are they theoretical?*
A. The plume models were developed from generalizations of actual hydrocarbon spills investigated. Monitoring points, observation points, source locations, discharge characteristics, volumes lost, rates of loss, soil and bedrock properties, water-table conditions, flow properties, and recovery activities have been documented in actual case studies. The generalized plumes have therefore been supported by actual field evidence. This data indicates that hydrocarbon dispersion is strongly influenced by the hydrogeologic conditions that exist at the spill site. These characteristics permitted us to locate the source when one was not originally obvious, to predict dispersion directions, to select recovery locations and effective monitoring sites and to develop expert testimony for legal action.

Q. by K. Childs. *Wouldn't hydrocarbons move down into an aquifer if dumped in a recharge zone?*
A. It is probable that some of the soluble components present in hydrocarbons will be carried down. However, the water table actually acts as a barrier, greatly inhibiting downward flow. This causes the shallow ground-water flow system to have a major controlling influence on dispersion. The amount carried down to the deeper system should be negligible. The key is to remove the product from the soil and shallow-water system as soon as possible. Once this is done, dilution should render the soluble remnants harmless. Practically speaking, this is more difficult than it sounds and may take several months to several years. Local conditions and the effectiveness of the recovery program will determine the actual outcome.

Q. by J. Wilson. *European studies have shown that hydrocarbon movement in the subsurface environment depends on the viscosity of the hydrocarbon, thus gasoline and fuel oil behave differently. Have you observed this and what differences are there?*
A. As indicated in an earlier answer, viscosity is one of many factors which play an important role in dispersion. I concentrated on some of the hydrogeologic aspects of the problem in this paper. My point is that once any hydrocarbon contaminates ground water, the hydrogeologic characteristics at the site become most important in controlling dispersion. Viscosity seems to limit dispersion only in the sense that more viscous oils are held by the soil to a greater extent. We have not noticed any differences once ground-water contamination has taken place. Of course no control spills for comparative purposes were available. Gasoline and fuel oil such as heating oil and number two fuel oil seem to behave similarly. Dispersion is usually rapid and recovery is difficult. More viscous oils, such as crude oil, are retained by the soil to a greater extent and relative dispersion is drastically reduced. In any case, the product must be removed from the ground to halt the continuous leaking of hydrocarbons to ground water.

Q. by D. Kirby. *What is the simplest and most accurate test for low-level hydrocarbon contamination of ground water?*
A. We have found that odor is the best field method. The average person is able to smell gasoline, for instance, from .1 to .5 ppm which is lower than it can be tasted. This is almost below the threshold of chemical identification. It is best to use the hot water tap in homes for this purpose since the greater temperature volatilizes the hydrocarbon so it can be readily identified. The cold water tap may show no evidence of contamination under similar circumstances. We also have had success using gas vapor detectors. They have been used to identify the extent of contamination under shallow ground-water conditions and to locate the source of leaks. Chemically, the hydrocarbon can be classified by type, i.e., gasoline, fuel oil, and creosols, at less than 1 ppm. The hydrocarbon is extracted in our laboratory by 1 liter of iso-octane and infrared and ultraviolet analyses are run. Gasoline has been identified from as little as .5 ppm. Brand identification requires greater concentrations.

Q. by D. Kirby. *Can different brands of gasoline be identified?*
A. We have had success in differentiating various brands of gasoline. The use of special filters with gas chromatography, in combination with infrared and ultraviolet analyses revealed differences in composition which have identified many brands. Public disclosure of the methods used is not desirable. We will share our results with other State protection agencies upon request, however. We have also explored the possibility of forcing distributors and service station operators to use tracers which could readily be identified; however, problems with tracers, required concentrations and the trade

secret that service stations switch brands occasionally when they cannot be supplied through normal channels, made the effort of questionable value. We also feel that if sample concentrations are sufficient enough to identify the tracer, then the product can be identified chemically. Colorado is evidently attempting to assign tracers to service stations. It will be most interesting to see their conclusions.

Q. by J. Turk. *Have you developed design criteria for underground storage tanks? What do you think of vaulted systems?*
A. The serious consequences resulting from hydrocarbon spills make safety backup systems absolutely necessary. In Pennsylvania, the State Police Fire Marshall's office has control of subsurface storage tank installations. I am presently working to expand these regulations to protect ground water. In the course of these activities, vaulted systems were considered. A vault must support the weight of vehicles and must be impermeable. The use of concrete vaults was discarded. Concrete is expensive and though it meets the strength requirement, it may crack. Asphalts are soluble in gasoline which makes their use undesirable. However, other types of liners are available which may be acceptable. I have not completely decided on how to best develop this regulation yet, but environmental isolation will undoubtedly be required, combined with an inexpensive alarm system which can be placed between the liner and the storage tank. Monitoring wells may also be included. The best prevention is proper maintenance combined with regular pressure testing.

Q. by J. Turk. *Have you developed monitoring techniques for detecting spills before they have a chance to contaminate aquifers?*
A. Monitoring hydrocarbon spills is a difficult task. A viable system for pipeline spills would require a large number of wells, while transportation spills would be impossible to monitor. Subsurface heating oil storage tanks at private residences could be monitored but first a mechanism to locate all of them would have to be established. Thousands of these tanks must exist. As I indicated in my paper, there are over 11,000 service stations in Pennsylvania. This would result in a minimum of 44,000 quarterly reports per year if each had only one monitoring well. Add to this the number of storage tanks used for industrial and other business types and the number of monitoring facilities increases. Bulk storage areas will also require monitoring. Though the task may be tremendous, it is expected that most of the above will eventually be required. It will be a very large undertaking.

Q. by B. Kent. *Comment on gasoline discharged from transport trucks when they have more gasoline than the service station requires, i.e., they sometimes dump it in ditches and etc.*
A. We have not come across the practice in Pennsylvania. It could account for some of the cases we have where no apparent source can be identified. I will check provisions for returning unused gasoline to the distributor. If no method of accommodating the returned product is available, then perhaps we, the State, should forcefully suggest that one be developed.

Q. by J. Fryberger. *What liability was assessed against the service station owner in the case of the demolished house?*
A. It is the Ground Water Section's responsibility to insure that the ground water is returned to its original quality. Product removal in this case is still in progress. Unfortunately, we were unable to prosecute for environmental damages due to technicalities. An out-of-court settlement was made between the home owner and the insurance company representing the responsible party. To the best of my knowledge, no further legal action was undertaken.

Q. by J. Fryberger. *Is the State prosecuting spillers?*
A. The Pennsylvania Clean Streams Act provides for prosecution when "waters of the Commonwealth" have been contaminated. This supplies us with a very strong lever. We usually prosecute when cooperation is not being obtained from responsible parties. Court action has been taken and fines have been levied in a great many cases, enough so that respect for our authority is guaranteed. Due to the time involved in prosecuting a case, we prefer to use this advantage only when necessary.

Bull Session — Operation and Maintenance of Domestic Waste Disposal Systems Discharging into Ground Waters

Session Moderator: Steven N. Goldstein, Associate Director for Management and Technical Assistance, National Demonstration Water Project, Washington, D.C.

Steve Goldstein, Moderator: Just to set the record straight, this is the Bull Session on Operation and Maintenance of Domestic Waste Disposal Systems Discharging into Ground Waters, corresponding to Session No. 2. The topic of Session No. 2 was the Operation and Maintenance of Domestic Waste Disposal Systems Discharging into Ground Waters.

There are a few procedural rules that I would like you to follow. The general procedure here this evening, which absolutely must be followed, is that when you speak, please speak clearly for the recording, number one; number two, the first time you speak please identify yourself by name and affiliation. Thereafter when you speak you need only identify yourself by name. But you must identify yourself every time you speak.

Sitting to my left is Sheila Willett, who is recording you on mag tape and taking down what you say in shorthand. Given the subject matter, I suspect that she's going to be dealing with some very interesting brief forms this evening. A brief form, for the uninitiate, is a little shorthand-shorthand.

I'd like to start out by having the speakers from the session this morning field some of the questions which they did not have time to answer on the floor. Ken Childs, would you like to lead off with some questions that you were asked and give an answer, or did you answer all of them?

Ken Childs, Michigan Department of Water Resources, Lansing: I believe I answered all of them, unless there are some more.

Steve Goldstein: Okay. Grant Kimmel, did we ask any of you that you didn't answer?

Grant E. Kimmel, U.S. Geological Survey, Mineola, New York: Yes, here's one. "What amount of nitrification or denitrification took place at the air-water interface below the landfill itself?" That was from Gary Small of the Salt River Project. Unfortunately, we don't have any information on the interface between the landfill and the ground water. We have only information downstream or downgradient from the landfill itself. We suspect that some denitrification did take place, because the nitrate content of the ground water is nil in the plume itself. Ammonia is somewhat high near the landfill, about 90 mg/l, and it decreases downgradient. The decrease could be due either to adsorption, denitrification, or dilution; and who can be sure what? What more can I say?

Steve Goldstein: Are there any questions about the answer?

Grant Kimmel: Or any questions about nitrate at all? It's kind of interesting, I might say here, in relation to the Babylon landfill that the plume represents a nitrate-poor area in the ground water in comparison with surrounding ambient ground water. The ambient ground water is over 10 mg/l, generally.

Donald B. Aulenbach, Rensselaer Polytechnic Institute, Troy, New York: I just heard the end of what you said and I wanted to confirm this, that it is either adsorption or dilution or both, because I just finished reading over a thesis by a student in Maine who did a study on this, and his conclusion was that it was desorption, and he didn't give any credit to dilution, which we really don't have a good handle on—how much might be dilution. And until we know definitely, I think we have to say it just the way you said it.

Grant Kimmel: Yes.

Don Aulenbach: I have tried myself to run a nitrogen balance, and it's the hardest thing to do. The nitrogen applied from the sewage treatment plant effluent just wanders all over the place, depending upon the operation of the treatment plant. And then, of course, if you have any denitrification, how do you measure this in the field? It's almost impossible.

Grant Kimmel: We ran denitrifying bacteria, and there are plenty of denitrifying bacteria prevalent in the plume water.

William A. J. Pitt, Jr., U.S. Geological Survey, Miami, Florida: I had a 4-part question I wanted to direct to you, but should I wait on that?

Steve Goldstein: Would you like to identify yourself and ask your question?

Jack Hamshen, Hazardous Waste, EPA, Washington, D.C.: I was just curious, the polio virus, was that inactivated, the virus that was introduced?

Bill Pitt: It wasn't an activated virus. It was the type of polio virus that you get in your normal vaccine. It was an attenuated virus. It's not—well, viruses are never dead, never alive, really. A virus is nothing more than—

Jack Hamshen: The protein sheath—

Bill Pitt: Right, you have an enzyme and the protein shell. And to what degree it was attenuated, I really don't know.

Jack Hamshen: It was the vaccine type?

Bill Pitt: It was the vaccine type, the polio 2 virus.

Jack Hamshen: The other one: your septic tank pH never exceeded 7.8; you said at 8 they released. Did you monitor this in the laboratory as well as in the field, or was this principally in the field?

Bill Pitt: No, the pH that we obtained was actually in the field. Now, the release rate of the pH was from the lab. The pH that we have, the maximum pH that we got of 7.8 wasn't really indicative of normal conditions, either. It happens just before these people in this particular home—they were getting ready to sell the home, and the housewife there decided to clean up the house. She used a lot of detergents, a lot of alkaline detergents. They, of course, went into the tank. That's when the pH shot up to 7.8.

Jack Hamshen: I see. And was there any isotope detection techniques used for the polio virus?

Bill Pitt: No, the technique for the polio virus analysis was actually a concentration of the virus with polyelectrolyte infiltration. We didn't use any isotope techniques.

Jack Hamshen: I see. Thank you very much.

Steve Goldstein: Grant, do you have any more questions you'd like to field?

Grant Kimmel: Yes, there is one submitted by Mr. Kazmann. "Are the conductivities measured at a single elevation, or is it some sort of average over the entire 70-foot aquifer?" The reference is to the slides showing contours.

Yes. The conductivities are measured at a single elevation for that slide that was shown. I have other conductivities at the shallow depth and the deeper one, but that slide was at an intermediate depth. At the deeper depth they're very similar to what they are at the medium depth. At the shallow depth the high conductivity zone extends a few hundred or a thousand feet from the landfill.

Lyle V. A. Sendlein, Iowa State University, Ames: How many wells did you have in your formation and at what different levels?

Grant Kimmel: Well, at the Babylon site the wells were generally at 3 different settings, the shallow, intermediate, and deeper. And there are a great many more at the intermediate depths than there are at the shallow and deep settings, because we could use what are called fire wells in that area. And there were probably in the neighborhood of 150 wells at the Babylon site.

At the Islip site the wells were far fewer, and we had as many as 5 different settings at the Islip site because the aquifer was much deeper. We didn't recognize the deepness of the plume until the second year.

Robert C. Palmquist, Iowa State University, Ames: Did you have fresh water coming in under the plume, towards the tip of the plume? Some of your data suggests you might; the federal description suggests it doesn't.

Grant Kimmel: I don't think so. I can't imagine how the fresh water would come in under the plume. What made you think that there might be?

Robert C. Palmquist: Your well No. 8 shows higher conductivities just above the base of the well, and it suggested that the plume was rising back up towards the surface.

Grant Kimmel: Well, if you saw this on a longitudinal cross section, you would see that in fact it doesn't do what you think it does.

Gerald Hendricks, SIECO, Inc., Columbus, Indiana: I would like to comment on this point awhile ago about nitrogen balances. We're doing some pilot plant work for sewage plant design. The intent is to nitrify the ammonia. We find there is considerable difference of opinion as to the proper test to use in determining nitrates. There doesn't seem to be any good general agreement as to the proper test to evaluate the nitrates so that you can make the nitrogen balance. It isn't unusual at all that the nitrogen can't be accounted for. It is disturbing because we often feel like maybe there is a loss of ammonia or some conversion to elementary nitrogen. But because of testing procedures, it's difficult to get a true, acceptable test.

Steve Goldstein: Bill Pitt, do you have any questions that you haven't fielded?

Bill Pitt: Yes, I had one question asked that I never did get a chance to answer. The question was, "How far from the bottom of the drain field was the water table at the 5 different sites?"

Well, the water table is about 7 feet below the land surface at most of the sites–6 or 7 feet or so. The actual depth of the drain field we really don't know, but we imagine that it would be somewhere between 2½-3 feet below the land surface. This septic tank was constructed about 15 years ago, more than 15 years ago, so it's a little hard to find out how deep the drain field really is. That is the question I have that I didn't answer.

Steve Goldstein: Grant?

Grant Kimmel: "Did your leachate move as a mass or as individual constituents?" This is by Ken Childs. I'm not sure what you mean, Ken. It moves as a mass, essentially. But there's –

Ken Childs: Did you interpret the whole thing moved out like a huge cloud, or did you see that it moved out to develop individual bifurcating patterns?

Grant Kimmel: I see what you mean–in relation to what your study has shown. The same plume can be traced by chloride and by bicarbonate, which are 2 individual ions that would be indicative of the plume, more than anything else. As for other ions such as sulfate, sulfate doesn't follow the plume. It can be very small at the landfill and very large at the terminus of the plume. And calcium, again, would not describe exactly the same plume, but it would not extend beyond the boundaries that we had chosen on the basis of conductivity. And none of these other ions, such as sodium, would extend beyond the boundaries that I have chosen on the basis of conductivity.

The second part of your question, how did variables in the regolith such as texture, fabric, and adsorption, affect the shape and extent of leachate migration? Well, I think that this aquifer where we have chosen to locate our sites is extremely homogeneous. Unless–there may be some inhomogeneity in relation to the direction of flow. In other words, there may be a preferential direction down the gradient, because this is the direction in which the deposit was laid down. There were no beds of finer sand or anything of that sort found in the drilling of the wells, so we assume that from top to bottom it was coarse sand.

Steve Goldstein: Randy Sweet, I know you have a lot of questions that you didn't have a chance to answer. Do you want to hit 2 of them now?

H. R. (Randy) Sweet, Oregon State Engineer, Salem: Sure. Stephen Ragone asked, "What conclusive studies can you site that show nitrogen in excess of 10 mg/l as nitrogen is a health hazard?" The reason that we use 10 mg/l is that it's the maximum acceptable limit for drinking water standards as defined by the U.S. Public Health Service. I think if you want to read a paper which explains the rationale, I have a copy of it here if anybody wants to copy it later, particularly Stephen Ragone. Winton, Tardiff & McCabe published a paper "Nitrate in Drinking Water" in February 1971 in the *Journal of the American Water Works Association* (pp. 95-99) explaining the rationale in the development of 10 mg/l as a standard.

The second question is from Fred Crates. It's a 2-part question, apparently. One, "Is cesspool technique the problem, or are you saying that all on-site systems are not adequate?" Now, I think when I addressed the problem of disposal in the East Portland area I tried to point out that the use of cesspools is certainly probably the most detrimental way that we could dispose of waste in the area in that the cesspools are not used in conjunction with septic tanks. Since urban development has taken place in the area, cesspools also take up a very small area, and this is one reason why they've been used.

The second part: "And if other on-site designs do a good job, what is the economics of on-site reclamation versus a central sewer system?" I'm afraid that we've reached the point in time in the East Portland area where the population density is so great that we don't have room to go in and put in separate drain fields for all these systems. I'm sure that if we did have properly designed and properly constructed septic tank drain field combinations, we wouldn't have near the problem that we have now. Unfortunately, there is no more room. The area is essentially housed and paved.

Steve Goldstein: We'll get back and get a few more from you in a awhile, Randy.

This morning both Rein Laak and Dick Otis alluded to some things that I'm not sure are generally well known to this audience, and I think they are very important. I'd like to say just a few words about them, and then ask the 2 gentlemen to comment and perhaps expand. They spoke about clogging mats and clogging layers in septic tank drain fields. A few years ago when we had the First Ground Water Quality Symposium, not too many attendees were familiar with the general construction of a septic tank system or any other on-site drainage system, and perhaps we could go through that just very briefly for introductory purposes.

Basically a septic tank is an underground vault, an underground box, constructed to be watertight—hopefully throughout its design life it is watertight. Unfortunately, even that cannot always be guaranteed. However, when the tank is properly constructed, and if the integrity is maintained the household waste sits in the septic tank for a day or so and undergoes various kinds of biological degradation to simpler biological substances.

The greases and other floating materials come to the top. The heavy materials and solids settle out in the bottom. On the bottom a sludge mat forms, and a good deal more biological degradation takes place in the sludge mat. And floating on the top is a layer of scum which includes a lot of fats and greases.

This can go on for many years, depending on the size of the tank and the degree to which it is loaded, and what goes in it. If you have a garbage grinder, you fill it up faster. If you use a lot of grease in the house and pour it down the drain, you're going to get into trouble. But that clear liquid in the center, between the floating scum and the sludge, is the only thing which should get out into the soil to be absorbed and further treated by the life in the soil, and also the chemical and physical aspects of the soil.

Now, when it's time to pump a septic tank, you pump it because that sludge in the bottom has risen up so high, and the scum in the top has come down so low, that there's a very, very narrow clear zone. So every time you flush or the washing machine goes on you pour liquid through that septic tank so fast that it scours out a lot of the sludge and carries it out into the field. And furthermore, since there's so little a volume of clear liquid in there, it doesn't stick around long enough to get good treatment.

Once out into the field, this relatively clear liquid, which is still pretty high in organic content and has—well, by definition, if it's septic it has no—almost no—dissolved oxygen. It has to get out to the soil, be absorbed by the soil, have some of its constituents absorbed on soil particles, have some of its organics removed by biological digestion in the soil, and have some solids removed by being physically strained by the soil.

In the process, the biological mat, or clogging layer, or jelly layer, develops at the interface in these trenches through which this effluent is carried through pipes—pipes with holes in them, preferably. Some people have been known to put in septic tanks and not use pipes with holes in them. And I can bring my pictures to document that little story; believe me, I've seen it. But anyway, the liquid goes through the pipes, out the holes, and into the bulk soil. At that interface, at the bulk soil, a clogging mat develops. Just a few years ago the very latest and most respected technological publications would tell you you've got to get rid of that clogging mat, you've got to minimize it, because it clogs up your system and the water can't get into the soil, and so it rises and you get these muddy lawns and smelly problems.

However, today we heard some of the newer thinking, which is borne out by some pretty critical laboratory and field work, which indicates that the mat is not totally impervious, that it performs good functions and good things, and as long as you design for it you can have a very good system. Both of these talks that we heard from Rein Laak and Dick Otis dealt with the very creative use of that clogging mat. And with that in mind, I would like each of you to perhaps expand on this a bit, on the points you think important. Rein, would you go first?

Rein Laak, University of Connecticut, Storrs: Okay. What we found out about the clogging mat was that the mat indeed was mainly biological. The mat would react to temperature. It would react to food load—the food load meaning nutrient load. As more nutrients were applied, the thicker the mat would be and the less permeable it would be (less permeable meaning it has more resistance to flow). Also, the mat itself breaks up sometimes. In other words, holes form in it. The theory about that is that inside the mat gases are released, carbon dioxide and what not, methane, hydrogen sulfide and so forth. This mat then will open at local spots, like the carpet here. You look at the black spots and say these are open and the rest of the spots are closed. So it opens and closes.

We also found out that resting the mat up to 3 days, or wetting of the mat constantly does not change the mat at all. We also found that if you double the hydraulic head on the mat, you will not get double the flow through it. It's not lineal. You saw the equation, the cube root equation, is the food load—you reduce the food load, in other words you apply pretreatment, you have a thinner mat, and you can have a higher so-called hydraulic conductivity through it.

Steve Goldstein: Well, what is good about the mat?

Rein Laak: The mat is a very intense biological barrier. The major oxygen demand is removed there. A lot of the bacteria are removed. As a matter of fact, maybe in some spots—you look at the black spots in the carpet, the bacteria will pass through there when it's open. The rest of the spots probably it will not pass through. And large colloidal particles will be strained out; they will be adsorbed. If you think of the mat as an upward flow, a flocculation type of a setup for municipal treatment, it will do a good job on virus removal, bacterial removal, and probably refractive organics.

Steve Goldstein: Thank you. Dick Otis, would you like to add to that?

Richard J. Otis, University of Wisconsin, Madison: There are 3 things that I'd like to mention. One is that we haven't found that the nutrient load does affect the clogging mat. This is something that we differ on with Rein. We don't know why, and so we're looking into it some more. Some of you may be familiar with the Wisconsin project. You know that we have this laboratory setup, we have a full scale treatment, septic tanks, aerobic units, and some others, and we are now beginning to load undisturbed soil cores with various effluents to see whether or not our previous experiments were correct.

The other 2 points that we found that do affect the mat are the underlying soil and the head. By increasing the head on the soils we can clog these columns up to where nothing will go through. The other point about the type of soil, we find that sometimes the more porous soils are the ones that will clog the most rapidly. That is because of their pore structure. Soils with larger pores do not have the capillary attraction to pull the water through the crust, so the crust becomes very effective in clogging. Whereas you go into a clay, it will pull the liquid through the crust, and as Rein pointed out it no longer becomes a clogging problem, it's a hydraulic problem. Hydraulics rule the design of such a system in clay. So there's gradations between. This is one reason why we have looked into pressure distribution systems. One in the sands, to spread the load out uniformly, try to prevent complete clogging, but more importantly to help purification so far as bacteriological constituents go.

Also we found that the silty sands cannot maintain their structure, and therefore clog fairly rapidly. We speculated that pressure distribution would help here. We have a system that we've been looking at. It wasn't a pressure distribution system, but it was a system that provided more uniform distribution. This is being used now, and may be of some help.

Rein Laak: I'd like to answer to Dick Otis. I'd like to ask the first question: How many tests did you run and how many soil columns did you have where you increased the head and you found there was complete blockage? And how many tests did you do resting and not resting, and the food load difference? How many columns did you test and how many soils? How many replicates did you have?

Dick Otis: Okay, the first part—it wasn't very scientific, I'm afraid. One of the professors of soils was looking at the problem of clogging and he wanted to get some cores with the clogging to look at ways of unclogging. So he had 5 cores of sands where he just kept a constant head of about one meter on them, and within a couple of months they were completely clogged. All 5 would not transmit any water at all.

In answer to the other part, we have undisturbed soil cores which we think are very important because of the pore structure again. The structure of the soil is very important. You have the worm holes, you have the root channels, all these things that you don't get in a packed column. And we're looking at the tighter soils. We had—I don't know the exact number, but it was upwards of around 20 of them. And we loaded them with various types of effluent, and we found no difference. In fact, the aerobic effluent was clogging somewhat faster than the septic, but we can't explain it. We don't know why.

What was that—you had one last bit to your question?

Rein Laak: The food load.

Dick Otis: I covered that.

Rein Laak: No, you said aerobic effluent. That's not food load.

Dick Otis: With dosing, with these tighter columns, we don't feel that it was making that much difference. In fact, eventually it did become clogged, and at the rates that we were loading, daily dosages, they would no longer drain away between our daily dosages. So that with the tighter soils we don't think that the resting is going to be a critical factor. Again because this has become a hydraulic problem rather than a clogging problem.

Dennis Gray, Southwest Idaho Health Department, Caldwell: Would it be fair to extrapolate this clogging phenomenon and apply it to this modified drain field where you can allow, let's say, 3 feet of filter media beneath a perforated pipe in order to save on gross area? What you said, if constant head increases clogging, it would seem to me to be the wrong way to go. Or at least a question about the way to go. Would it be fair at this time to make any statement?

Dick Otis: I don't know if I really understand, but I think you may be confused as to where the clogging mat is occurring. When you bring in fill, you're putting the trench up in the fill.

Dennis Gray: I was taking subsurface as opposed to surface.

Dick Otis: Okay.

Dennis Gray: The clogging phenomenon seems to increase with the head.

Dick Otis: That was true for sands, in increasing the head, yes. Strictly because of the pore structure. The pores are too large and they don't have enough capillary attraction to pull the liquid through, whereas if you had a finer sand or a silt loam or clay you would be able to pull it through. But your loading rate may not be as high. Again, the smaller pores are pulling the liquid through, but because they are smaller they're not taking as much water.

Randy Sweet: As I read—what is it, Bulletin 21 by Bouma *et al.*, re soil absorption?

Dick Otis: Bulletin 20.

Randy Sweet: Bulletin 20, I'm sorry. Anyway, we talk about mats forming essentially in all drain fields. It's a matter of time and a matter of the difference in the depth of different materials, different substrate. So, then, is there a difference in the hydraulic conductivity of the mat with the different substrates? In other words, if they're underlain by a clay or underlain by a more permeable material? In other words, is the hydraulic conductivity of the mat constant or is it something that varies with the substrate?

Dick Otis: It varies with the substrate. If you took the mat itself, took it away from the soil, maybe you wouldn't find any difference. But the soil underneath would make a difference, because they will be able to pull the water to the surface. Smaller pores can pull the water through whereas the larger pores can't.

Randy Sweet: So the hydraulic conductivity is constant, it's just the ability of the substrate to pull the water through the mat with a given hydraulic conductivity?

Dick Otis: I really can't say for sure, but that would be possible. Now, we have found that at higher loading rates the mat does become thicker. Now if you have more water going through, it will become thicker. If less water goes through, it will begin to decompose.

Randy Sweet: Then the next logical question is: Most drain fields have been sized based upon the hydraulic conductivity of the substrate, or the ability of the substrate to transport the effluent away from the drain field. Essentially you're saying then that it's been going backwards to a certain extent, in that a more porous material is not necessarily capable of carrying the effluent through the mat as well as, say, a silty clay loam or something like that.

Dick Otis: Yes, and no. If the system is sized too small, your loading rate is going to be too high and you're going to clog it. If it's sized properly even according to what the States have as their codes, it will probably function. The mat won't become that thick. But sands can clog it pretty effectively. It depends on just getting the right size field.

Rein Laak: I'd like to just clarify this, instead of sticking to my food load if the load is lower you have a low food load. If you have no food load you have no clogging. If you have a slow load, low food load, you have a lesser clogging layer and more liquid flowing through. If you apply more liquid, the clogging layer grows and controls itself, so it will control how much liquid it will let through.

So if you put a big head on it, you force it, it will become less permeable and less liquid will go through it. So consequently there's less growth. You have to wait for a period of time, and it will open again, and it will clog quickly again. You can't force through that clogging layer. The clogging layer reacts very quickly to it.

So the ideal design is to find the equilibrium with the load where the clogging layer is forming, and with the degradation rate or disappearance of this clogging layer. This will be a long-term acceptance rate to the clogging layer. The tests will have to be run a year or 2 years to find this kind of an equilibrium.

William F. Martin, Indian Health Service, Tucson, Arizona: I just wanted to get some clarification. Are you saying that the system designed a tile field in such a way that you completely fail the first lateral, and then keep it loaded and overflow into the second lateral and so forth, like a serial distribution system?

It's no advantage, in that my experience and some of the things I've read is that you have a longer life expectancy of the field if you leave a major part of it completely idle until you've failed a portion of it. And that idea seems to conflict with your mat problem. I'd like clarification. I'm not sure, were you challenging that if you load and fail a section of your field and then use the next and so on, it will not increase the total life expectancy of the field as opposed to a uniform distribution?

Rein Laak: You do not save the first field. What you do, you have overloaded the first field. The clogging layer still has—some liquid always travels through the clogging layer. It may be very minute. And then you proceed to the next trench. If it proceeds to the next trench, then, if you keep the same head on the first trench, the next trench fails. Also you have a minute acceptance rate on the second one, and you go to the third one, fourth one, and so on. And you add all those up, all those small increments, that is really the long-term acceptance rate of that field, that system. This is what you design for.

William F. Martin: My understanding is that this method of loading increases your total life expectancy of the field over uniform wetting of the field at one time, indicating that once the bacterial action or mat is formed throughout, there's some aging mechanism that sets in and decreases the soil capability to receive water. Any comment?

Rein Laak: Yes. We found it doesn't matter how you do it. In the long run you form a clogging layer, and its acceptance rate is very low. It may develop over 10 years.

William F. Martin: I'm not arguing that it will develop. Is the total capacity of the system any different?

Rein Laak: No, not in the long run; it's no different. There is no evidence to say it's different.

Steve Goldstein: May I try and clarify what he said? I think what Dr. Laak is saying is that if you start from the beginning and put clogging mat in each one of your serial trenches, were you to have done that, or were you to put a clogging mat in one trench at a time, that the design criterion should be that, at the very end of this process, you still have enough clogging layered trench bottom, with its much lowered acceptance rate, to accept your daily load of effluent.

Sooner or later it's going to clog. Whether it clogs in 10 years or 15 years need not matter as long as when it's fully clogged it's still passing a little bit, it's passing the daily load. That's the criterion we're shooting for.

Fred J. Crates, Hancor, Inc., Findlay, Ohio: Can you relate all this to the storage capacity of the trench itself in the presence of gravel? In other words, you start out with a certain amount of storage capacity in the trench, and then predict this clogging to occur. Are we not consequently reducing the storage annually, and doesn't this have some significance on the success of the system?

Rein Laak: If you have stones in the trench, part of the effective porosity of the stones will be reduced through the years, yes. The storage capacity in the trench, the way I do it, is for peak loads, once the clogging layer is formed. The problem is what to design the clogging layer for, for the maximum months or for the maximum days. Will it accept the maximum months or maximum days or annual average? The storage space is to take peak loads. And the storage space does reduce over the years as the mass, biological mass, accumulates in the stones. It does reduce.

Steve Goldstein: We have spent a good deal of time now on septic tank drain fields. Is there some other line of questioning that any of you would like to pursue? Randy?

Randy Sweet: I'd like to have one clarification. Laak seems to feel that it's the head–as I understand it–in the drain field that drives the effluent through the mat, whereas Mr. Otis here feels that it's the capillarity that pulls it through the mat. And I wonder, is it one or the other, or both?

Rein Laak: Both.

Steve Goldstein: One's a push, one's a pull. It doesn't really matter.

Randy Sweet: I wonder how it relates to design.

Steve Goldstein: Vacuum is a negative pressure.

Rein Laak: As far as design goes, if you can depend on capillarity during the wet seasons of the year, then by all means go for the capillarity. Add that to your design. But if you cannot depend on it on long run, where the water table may mound up underneath, then you have to provide a head on it.

Lyle V. A. Sendlein: I can't remember from your slides, Dr. Laak, if you were able to tell us what the hydraulic conductivity was of the area, or if this did vary. It seems to me that if it was a variable, how does it vary, how do you predict it? And if it doesn't vary, then really the soil type doesn't mean anything, and you can just design then on how big a load you're going to have applied to the field.

Rein Laak: Now you opened up a can of worms! We divided the problem into two, the soil and the hydraulic conductivity through the soil. And the second problem is the clogging mat problem. So you calculate one separately, and you calculate the other separately, and put the two together and see which one rules design.

The clogging mat is never really constant. What we're trying to estimate, we estimate somewhere around 10^{-4} feet per minute that it fluctuates. And in certain cases where you have high ground-water tables, and the soil permeability may be around 10^{-4} feet per minute, you have a high water table, or you may have a so-called impervious layer fairly close to the bottom of this, maybe 4 or 5 feet below, then you may have that the hydraulic conductivity below the clogging layer rules the design.

Lyle V. A. Sendlein: I assume you're saying that you designed this really on the 10^{-4} number?

Rein Laak: In reality we don't use a 10^{-4}. We have a curve, showed you on the slide, the overhead, today, the green line.

Lyle V. A. Sendlein: Yeah, I couldn't make it out.

Rein Laak: So actually the soil underneath is a supporting mat for the clogging mat. It doesn't matter what the soil is. The clogging mat more or less is the same. You can grow it on this tablecloth. And the only thing is when it forms the holes–the black spots on here–if the underneath is more porous, at that moment it lets through more water. That's why in more porous soils you can get a little bit more liquid through. But the clogging mat is the same; it doesn't matter what the soil is.

Dick Otis: Since we are here for controversy, I beg to differ with you. What we've done is gone into the field, and we've looked at a number of systems that have been installed in the field, and this is all work that was done by Johannes Bouma. I don't have the numbers, but I can sort of explain the conceptual aspects of it.

We looked at the various types of soils, sands, silt loams, the clays, etc., and through a technique that Dr. Bouma points out we can measure the unsaturated conductivity of the soil. And we know that with sands we start off with a very high conductivity, but as the soil tension below the clogging, as the degree of saturation drops off, you can't pull as much through this mat. In other words, the hydraulic conductivity drops; it just drops straight down and actually goes below the clays of the soil. You have a very unsaturated condition. The clays start very low, but they don't drop very far as the degree of unsaturation progresses.

We use these curves for design. For the various types of soils we found that clogging mats do develop, and the resistance or the soil tension underneath the mat will be different. And we can go back to these curves then and just go along the abscissa, which is the soil tension, up to the particular soil type, and then get our design loading, which gives us hydraulic conductivity, which is a very neat way of doing it.

We found that there isn't that much difference between the various silt loams. To a soil scientist there's all different kinds of descriptions for all kinds of silt loams. But generally for hydraulic purposes you group them all as one, and it comes down to about 4 or 5 different soils. We have developed these curves and we have the competence limits of these curves, and we think it will make a very good basis for design in these fields.

We found with the silt loams that we can actually load them about 3 times higher than what the State health code says. But with the sands, you have to stick pretty much with what they have. In the clays they don't allow them, and we feel that can get fairly excessive if you do install them. But it would function. It's like Rein says, you have to build the bed for the particular soil you have. You can have a series of trenches, and eventually you'll get to the last trench, all that you will need to take care of it. That will be your design.

Rein Laak: This is the last time I'm going to say anything, then everybody else can talk. The crust test by Bouma is very interesting. The crust test measures the unsaturated flow. It measures in between. It does not measure the flow through the crust. It also measures the flow, actually, underneath it. Our feeling at the University of Connecticut is that this type of a measurement is fine for functioning fields and what the behavior is. But design, as a basic design for long term, and using the worst conditions, we feel that test should be modified and the test should be changed so that you measure actually the transmissivity through the clogging mat, not underneath it.

Dick Otis: In answer to that, in a sense you're right in that we're actually looking at the flow through the soil underneath the mat. But the water is coming from above the mat and therefore it's got to go through it. And the amount of water passing through the soil with the various crust resistances that we apply across these soil columns in situ—we're trying to determine how much is going through.

Steve Goldstein: Well, Laak promised he wouldn't say anything else about that, and Wisconsin got the last word. But then again, Wisconsin makes great cheese!

Steve Sisk, EPA, Kansas City, Kansas: I'd like to introduce a topic that I haven't heard anything about since I've been here. It is of some interest in our region. That is nonconsumptive spray irrigation. Is there anyone here who has had experience with contamination problems resulting from nonconsumptive spray irrigation? If so, I'd like to know what they are.

Steve Goldstein: I could suggest that Bill Walker would have something to say to that, and Bill is probably in another room. I can do more than suggest that, because he took me to task over some items when I wrote about them a few years back.

Robert Ward, Colorado State University, Fort Collins: One of the things in Colorado that we have a lot of trouble with in the mountains is the shallow soil layers in which to install leach fields. What is the minimum amount of depth of permeable material that is necessary in order to adequately treat waste water? I'll throw that one out.

Steve Goldstein: You just reopened a wound that I thought we had sealed! Does anybody from the audience want to venture a guess?

Donald Aulenbach: I can't venture a guess. But with the studies that we are anticipating doing at Lake George, we have some sand beds which are used for recharge, complete tertiary treatment of a secondary treatment plant effluent, highly filtered effluent. As of the moment we have installed well points every 2 feet down to 15 feet, and we will be installing lysimeters every 5 feet down to the ground water, which is about 65 feet. And I hope within a year we'll have at least some information on the type of sand that we have, which I don't say is applicable everywhere, but maybe we'll have an answer within another year.

From the studies that we have done some years back, 10 feet of sand, vertical, has about 95, 99 percent BOD removal, and about the same 99 percent coliform removal. And by extrapolating, we would assume that maybe 15 to 20 feet would have given us complete ammonia oxidation and/or removal. I forget the other parameters. Phosphorus was reduced, but not removed in that distance.

Ken Childs: I would like to throw out something as a suggestion. As geologists we talk about sands and clays and gravels, and we frequently infer mineralogy exists. And we would like to use the term "clay," and at times it means one thing, sometimes something else; other times it means size. Depends on whatever the need is.

More specifically here, I feel that you talk about 10 feet of sand or 4 feet of something, the relationship has got to be between a constituent and a particular type of material. Now, there may be sand size, it may be a sand of a particular chemistry, for example, and 10 feet of sand may be adequate in terms of ammonia nitrogen but it may not be adequate for phosphorus. So it's not simply a question of a number for a sand or a number for sewage, you've got to be specific about which constituent and specific about the environment that you're putting it into in order to apply that type of rationale, I believe.

Randy Sweet: I assume we are still on the question of the depth of materials needed. I pointed out in our report that on our study we found that 200-feet wasn't sufficient depth when you have a cesspool type disposal system. I could carry that a little farther and say that on the Oregon coast we looked at some systems and we found that in one particular county we have something like 46 percent failure in the systems located in the dune sand and the terrace sand along the coast, and that the sand is generally a very sterile medium in that case. And when I say "failure" I mean bacteriological and chemical failure, and that's on the beaches and some places. Most of these, however, are associated with commercial establishments. So I think you also have to put a loading rate into this thing, which we haven't mentioned yet. The loading rate also goes into that in this 200-foot separation I was talking about earlier. We have a very high density population in the area. You've got a lot of water, a lot of effluent going down.

Steve Goldstein: Was the flow in those cases of 200-foot separation, and/or the beach, was the flow in the soil regime saturated or unsaturated?

Randy Sweet: In the beach we can't be sure. In the Oregon coast, I don't know if everyone is aware of it, but we have quite a bit of precipitation in the winter time. We actually can get a slugging of material going to the water table that's discharging. In the Portland Terrace area that I was talking about earlier, we feel that we're talking about unsaturated flow.

Ken Childs: I feel that it's not per se a distance concept, it's a time concept. If you put so many pounds into a system of some dimension having specific characteristics, then that system has the potential to remove X pounds of that constituent. And when that constituent and that filter are saturated, at that point there's no filter left. So I think it's a time concept more importantly than a distance concept, tied to loading and specific characteristics of that particular part of the system that is acting as a filter.

Randy Sweet: We carried that a step farther in some of our studies, in fact with the nitrates. It's not just the time and an ability to treat, it's also a dilution ability. It's the same thing that they use in the airshed plannings, and in some of the surface-water quality—to balance things.

Ken Childs: I would suggest that dilution is not in essence treatment, but dilution is only—you have the same load when you get done, whether it's 5 parts per million or 10 parts per million. The only thing you've done is to spread it out. Dilution is not treatment.

Randy Sweet: I would just say that there is a school of thought that says dilution is the solution. If you can't measure it, then it's not a problem.

Gerald Hendricks: I think the gentleman from Michigan said something really important in talking about constituents. I think we're missing something. No agricultural engineer that I know of that can think would overload the soil with nitrogen to the point where you would have an excessive problem in the ground water. He's wasting fertilizer.

Some releases say that by 1980 we will not have the fertilizer plants we need to meet the food problems. I know farmers that buy fertilizer $10,000 at a time. So I'm not negative about application on land. But I'm a little disturbed by the tendency for us to ignore the people who are specialists in this field, the agricultural people, and so I feel like this constituent loading should be related to the vegetation that is using that soil.

I feel like in the nongrowing season, let's say by absorption you are storing. But come the growing season you better use it if this thing is going to be a balanced situation. So I think that Mr. Childs is saying something very true when he talks about the constituent loading, rather than the distance, as being what we should be looking at.

Steve Goldstein: Thank you, Gerry. I would like to make this observation. Not too long ago, and still today in many places, people feel very safe, secure and content by reading in a book that wells should be 100 feet or 50 feet, depending on the location, away from a septic tank or drain field. And if the regulation is written as 100 feet required separation, they feel very safe at 101 feet and very insecure at 99 feet.

I think that all of us today, with the things that have been batted back and forth, now see that such rote formulas are really sheer folly. There's a great importance in sanitary engineers, soil scientists, geologists, and yes, Gerry, even the ag engineers, communicating back and forth about these things, but that really rote formulas have to be on the way out.

Rein Laak: I'd like to defend the rote formulas. The rote formulas have a good application on this. Until there is a clear and universal understanding of treatment through soil, there is uncertainty over which constituent you are looking for. And some kind of a soil test to know how well the soil can treat.

The codes specify minimum distances. They specify only minimum distances, which is a type of minimum protection to the general public. And it is up to professionals to decide whether this minimum is sufficient or not. And there are many cases where it should be longer than 75 feet or 100 feet. Although, when you do propose it, the code in a way has a double edge. When you propose 200 feet, your client will say, "You're crazy, the code says 75," and you have a tough time convincing anybody you need 200, because we do lack a soil test to predict what constituents, how far it goes, and also an economic way of investigating a soil site or investigating an area economically. There is none available. It takes an enormous amount of money to investigate an area.

James R. Gentry, Memphis/Shelby County Health Department, Memphis, Tennessee: I think the cost of land is such today that we can't justify depending upon the formula that you have to be 100 or 200 feet away from a source of contamination. We have a good overburden of clay there, and I'll approve a well within 25 feet of a septic system if it's put in right, if it's properly protected. If the space surrounding the casing is properly protected, then you don't need that distance. It's the cavities surrounding the casings that are creating the problems in a lot of areas with contamination.

Bill Pitt: I'd like to come to the defense of dilution, mainly because that's what we did in Miami. We found out that dilution was indeed the major factor that had any real weight when we're talking about the parameters that we looked at. I realize that here you're talking about distances and other things, you're talking about sandy areas mostly, clay areas. But in limestone areas, dilution is a very important factor.

Steve Goldstein: Do we have any answers or comments directed toward the gentleman's comment about a 25-foot separation and so forth?

Ken Childs: Do you give any significance to the depth of the well itself, whether it's 15 feet from ground level, or whatever your minimum is, or if it's 200 feet or 400 feet? Does this have any significance in terms of the horizontal isolation between that septic tank and that water well? And also, whether or not the septic tank is upgradient or downgradient, is that a consideration?

James R. Gentry: Yes. It is a requirement that the well be located at a higher elevation than the septic system. Also it is considered, in that most of the formations that I was speaking of are 90 feet or 500 feet. We have a shelf at 90 feet, we have a 500-foot formation and a 1500-foot formation. This is a consideration. The well is required to be located upstream from the septic system, and surface water is required to be diverted from the area of the well. And depth is a consideration, and the amount of overburden that you have, and the type clay formation, and so forth.

Randy Sweet: To be pragmatic about the whole thing, I have worked with the development of the rules in the State of Oregon. I don't agree with a set distance to the water table or a set distance to a well or a set distance to a septic tank. But the people who are evaluating these systems we have found are not always capable of completely understanding all the hydrologic and hydrogeologic implications of a waste disposal system, and therefore we set up a set of rules but cannot always—and I'm sure that every other State has done the same thing—set up a set of rules which we hope will have a safety factor involved in the rules which will allow for some practicable solution.

Unfortunately, and I'm sure it's happened to most other people involved in the same kind of business, we are not allowed to talk about density at all, because we are not in the "land-use planning" business. And therefore we run into a lot of problems like the one that I talked about in East Portland, I think, where the density becomes so great and the loading becomes so great that, as I said earlier—and I didn't claim to be a proponent of the school that dilution is the solution. But where dilution is not the solution any longer, in fact it's becoming a problem. We don't have sufficient dilution.

Steve Goldstein: By "density" you meant population?

Randy Sweet: Population density. Or disposal system densities.

Thomas I. Iwamura, Santa Clara Valley Water District, San Jose, California: To that regard, concerning density, is there a way to even begin to determine so-called threshold density, as to what level of development can an area develop? I realize that we're talking about both the alluvial areas that concern the ground water, and then the mountainous areas. For instance, in an alluvial ground-water basin area, is there a way? I guess most people know Santa Clara County is one of the fastest growing counties, and the city areas are growing very drastically. But there is a great amount of pressure to grow in the county areas.

They're starting out with, for instance, minor subdivisions, 4-lot type, total of 10 acres divided up into 2½-acre lots. Offhand, one here or there really doesn't pose any problem. But from a county standpoint, if we can allow these things to go through and this spread becomes uniform throughout the county area, how do we know that this is permissible or not? Is there a way that we can evaluate this? I'd like to throw this out.

Steve Goldstein: That is an excellent question. Does anybody care to hazard a guess? He's talking about a rational approach toward limiting the use of on-site disposal, primarily through septic tanks, or coming up with a limiting or maximum permissible density of population, based on physical, geophysical, hydrogeological considerations, with the objective of minimizing the contamination of ground water or keeping it within acceptable limits.

George B. Maxey, Desert Research Institute, Reno, Nevada: You put it on a scientific basis; he sounded kind of emotional.

Steve Goldstein: But I don't have to face the builders that he has to face every day.

George B. Maxey: He's quite emotional. I face these things every day, and I wonder why he is so emotional.

Tom Iwamura: I face the problem.

James R. Gentry: I think that the situation is such that you can limit the density for septic systems. If they go beyond this limit of density, then they have to go to secondary treatment.

Steve Goldstein: I think the question was, how do you determine for any given area what the limiting density should be.

James R. Gentry: It depends upon the soil formations in the areas.

Steve Goldstein: Rein, if you recall, we both attended a meeting where one of your colleagues at the University of Connecticut came up with a model for just such a thing. Could you identify him and go over that briefly?

Rein Laak: Yes. University of Connecticut's Professor Tom Holtzer is a geologist, and he did some modeling on this thing. He used nitrogen as a basis to come up with a density, and using minimum ground-water flow, low flows, and ground-water contamination by nitrate, to try to calculate what the limit should be, assuming septic tanks.

Now, my personal opinion is that we should not seek that kind of a planning tool, because on-site disposal technology is developing. Other types of pretreatment units, other ways of manipulating treatment before it reaches the ground-water table can be achieved, so that you should not provide the planner with a tool, zoning, which has a far-reaching effect, so it can be implemented.

Rural living or suburban living should not suffer because of, I would say, antiquated technology, which is just about moving ahead now, and more information is coming up, so I don't think we should be thinking of basing population density on septic tanks. Just leave it open.

Steve Goldstein: Okay. At least we have identified Dr. Holtzer, and that's a start. Jim Warman, could you comment on the question?

James C. Warman, Water Resources Research Institute, Auburn University, Auburn, Alabama: The comment begs the issue that technology is developing, but is not developed. He has a problem today.

Tom Iwamura: I'd like to add a little bit to this. When I talk to our County Health Department concerning the new technology and concerning pretreatment or upgrading before it goes into the leach field and these things, their stand at this time is that they're very reluctant to give just a general okay on this. They realize, it's just like on any septic tank, it depends upon that system itself. Is it performing the way it's supposed to? And our County Health Department has indicated that we just don't have the personnel to go out and check every one of these.

William Martin: That just brings back a point, Steve, that I wanted to sort of challenge you on, is that not wanting to put out these guidelines, these numbers, distances, and so forth, because we need a team of experts to evaluate these sites. I don't think we'll ever have that team there. We can't afford it out on every site. And if we can't come up as professionals with some guidelines that zoning people can use now, and modify those as we gain better knowledge, we're not worth our salt. We should come up with those guidelines for these guys. That's what we're working for, so that they can get going.

We're putting in systems right now that we don't have technicians out there seeing that they're put in right. It bothers me. I design a system, I go out 2 years later and find out that half the field was put in. We're not even putting in what we know about right now. It's very disturbing. I think we have an obligation to people like this.

Steve Goldstein: That point is very well taken. When I was referring to rote formulas, I guess I was referring to a rigid description of something like 100 feet irrespective of any other conditions. Now what you're talking about in terms of guidelines, where indeed there is some interpretation and there is not just one answer, but there is an answer which depends on other conditions which a person with only moderate expertise can evaluate, that's the kind of thing that I'm looking for, and I think that we're not talking about different things.

Tom Iwamura: The thing that I would like to really put on here is that unless we come up with something, the politicians will steamroller us. It is an awkward position to be in. But unless we can realize the problem, we can look at it on the basis of mass salt balance and things like this, we've got to be a little bit more specific and a little bit more practical. And unless we can get it down and convince the politicians, they're just going to steamroller us until we can prove that it is harming the basin, and at that point it might be a little too late.

Like for instance, some of the earlier talks this evening that they had densities like about 4 septic tanks per acre and it was creating some problems. It's creating problems up to a certain time. But time doesn't stop; it keeps on going. And then what?

Donald B. Aulenbach: This is another situation where we are saddled with the problem that somebody, usually the Health Department, has to make a decision without adequate information. Of course, this is something we do all the time. The one thing that to me is the biggest problem, in actuality there should be no requirements for any distance between a well and a septic tank, because proper septic tank disposal says that we discharge the liquid effluent into the surface ground-water supply, this is the ground water in contact with the surface at the top layer; whereas a proper well will never take water out of the surface ground water. In other words, it will pass through at least one aquaclude or impermeable layer before you extract any water.

And assuming that the wells are properly constructed—which they may not be—there will be no interchange between the aquifer from which we are taking the water and that into which we are discharging the water.

Donald Keech, Michigan Department of Public Health, Lansing: This brings a point that I want to ask. What is a protected ground-water supply? Now, this has to be considered along with the spacing or lot size of your subsurface disposal system. For example, many areas, as Mr. Childs knows because we've discussed it, in Michigan you don't have an aquaclude. You've got sands and gravels to the depth of the water-bearing formation that is potable. Is a 75-foot well, say, with 30 feet of water above the screen, a protected water supply with a reasonable horizontal separation from the sewage disposal, on-site sewage disposal?

Steve Goldstein: Can anybody answer that question before asking another?

Arthur Clarkson, Montana State Department of Health, Helena, Montana: We have similar problems in Montana, and we have taken the attitude if you are below 50 feet and you have sand and gravel all the way we're going to have to approve it, and if it gets too bad you're going to have to chlorinate the well. And we have many, many areas where you have 50 to 75 feet of gravel over bedrock that was formed when the glaciers moved through, and this is the only source of water they're going to have. And there's no other way to get rid of the sewage, so you're going to have to use something like it.

Tom Iwamura: It's something like that, it's something like the ball is in progress, it's rolling. I think a monitoring system has become highly important, not only to know what the water quality condition is, but what is the trend, even though it is within safe limits. But as soon as an adverse trend begins to occur, you've got to either take some action or you'd better look into this very deeply.

Ken Childs: Well, in Michigan, many of the water supplies are in water-table conditions, water-table aquifers. Most of the sediments are glacial sediments at the surface. So the clay is identified usually from well logs, and the well logs are written up by the driller who identifies clay on the basis of size. There's an interpretive factor in each well log. But the presence of clay in one well log does not insure the continuity of clay beyond that well bore. And like I say, in many cases there's no aquaclude involved.

Getting back to the depth, I can show you cases in Michigan in outwash, 70 feet of outwash, and many wells in a small village where there's 70 feet of sand and gravel above a water-table aquifer, and the wells are completed in the top of the aquifer because that's the cheapest way to go, and that's the way we do, cheap. And most of those wells in that village show some influence of sewage. But we don't have the luxury of "the aquaclude." And you can't guarantee continuity from well logs.

Richard Slade, Geotechnical Consultants, Inc., Burbank, California: As a practicing engineer and geologist I appreciate the necessity of well standards as Mr. Sweet suggests. I also can appreciate the gentleman from Santa Clara's necessity to have a practical solution. We get, of course, involved in this all the time to provide answers to clients who have problems. And in Southern California there's the magic number of 50 feet for a well seal that we have to deal with every day. It's a sanitary seal that's supposed to be the cure-all for everything. But we get involved—for instance, one of our projects was in the San Bernardino Mountains near Lake Arrowhead where its granitic materials, there's no interstitial or intergrain processes for permeability, so you're dealing again with the fracture permeabilities. The State says, "Well, you've got to have a 50-foot well seal and all your horizontal wells are therefore no good because you don't have 50 feet of cover in the moutain mass over some of the seepage pits."

So we said, okay, we'll try to go along with that. So we decided to try some vertical wells. And in the typical mountain mass the way the fractures have been running the horizontal well is the only solution for a water supply. The vertical well, if you drill it, you don't necessarily intercept as many of the fractures, and yet you can obviously get a 50-foot well seal. It's much easier to get one. But in all actuality, when you're dealing with fracture permeability, it doesn't make a bit of difference whether you're horizontal or vertical because the fractures, you're going to get them across the well. So it's very difficult when you're fighting the system to get the client water. They're dealing with fantastic quality water. Up in the mountains there, TDS's (total dissolved solids) are 70 or 80 parts per million. So you're dealing with these problems. Yet the State says you've got to deal with this 50-foot well seal and therefore you can't have a horizontal well any longer.

So, again, how do you fight that problem? So you have the standards on one hand, you have the practicalities on the other. One further example we deal with in the counties there is abandonment of wells, and the procedures. You have a lot of old farmers' wells out in the alluvial basins, long since defunct, and the farmer has thrown his little bit of dirt in them and some rocks every now and then to cover them up. And years later someone is grading there and hits the well casing and you've got 400 gallons a minute flowing on the ground surface. So then someone says you've got to shut this well off or you're going to occlude everything.

And we're called in to shut the well off. And we have some regs, we can do this. But now we have to fight the Department of Health, because the Department of Health has an exact set of guidelines on how to abandon wells in certain areas. And we get involved there with a representative from the Department of Health coming out and telling the contractor or an engineering geologist how to shut a well off. He has an exact list, a formula, if you will, of what to do.

And it's been our experience in this case that we don't feel the Department of Health ought to be handling this. It ought to be people in the government branch who are the inspectors, but in this case the inspectors are in the wrong county department. They're in the Health Department. Their backgrounds are not such as the contractors, they don't have any engineering experience, and this becomes a serious problem. And we've had to fight the system, and most of the time we actually end up winning. But again, the standards versus the practicalities. And this is very serious.

Jim Warman: We have as part of the well construction standards a concern about closing wells. These regulations were written with the input from drilling contractors who are members of the regulatory board. And yet these people in their wisdom overlooked something when they said, "If you're going to seal a well, you're going to ideally fill the thing with grout." And yet their same regulations permit bored wells. And there's no way under the sun that you're going to convince a fellow with a rig that bores a well that he's going to fill a 24-inch hole with grout. So that even when you have this kind of input there will be mistakes made, and then you have to go through the rather formal procedure of revising these regulations. It's a rather formidable task.

Steve Goldstein: For the record, Jim, would you identify the regulations or the proposed standards?

Jim Warman: This is a regulation of the Alabama Water Well Standards Board. These regulations are, of course, up for revision. The board has been made aware of this particular fault in the regulation, and in due course they will take care of it. But I recall it was about a year ago that I called that particular problem to their attention, and it hasn't been fixed yet. I would hate to see them try a court case to force some fellow to fill a 24-inch or a 36-inch or whatever bored well with concrete.

Steve Goldstein: To your knowledge, is this subject addressed in the proposed well construction standards that the NWWA has put together for and with the cooperation of the EPA?

Jim Warman: I can't answer that one.

Steve Goldstein: Do we have somebody here that can?

Wilbur J. Whitsell, Water Supply Division, EPA, Washington, D.C.: The so-called specifications on well abandonment as they appeared in some of the first drafts of the NWWA specs did not meet with approval of a number of the contractors and other people, and so a number of us sat down to see if we couldn't come up with a more general and a similar recommended procedure for the abandonment of wells which would cover virtually all cases. This primarily is based on using common sense in following these procedures and not insisting, for example, that you put in cement grout in regions where it's not required. Now there are some catches. One of the main problems in abandoning any well, of course, is that you may be abandoning something about which you know very little. And if you have the information on the geological formations that were penetrated in the construction of the well, it suddenly becomes relatively simple.

To give you an idea of the way it stands now, and I have to add to this there is a possibility this could still be changed, we feel that within the aquifer zone itself there's no point in putting a material that's a sealant in a formation that is permeable. The formation might just as well be filled. We're talking about filling, backfilling, rather than sealing. It can be backfilled with a material that's similar to what is in the aquifer formation itself.

For example, if you have penetrated a sand and gravel aquifer, then we feel that a sand or a gravel which has been disinfected—we prefer it be disinfected—you can do this with sand and gravel—can be used to fill that zone. Then in the impermeable zone, if there's an impermeable zone above that, then you should use a cement seal or a plug. Above that we don't really care a heck of a lot, as long as whatever is used in the fill, the fill material above there, is less permeable than the material around it.

Don Keech: I feel that Michigan has a very practical well plugging regulation, and in response to our contractor from California, I am an engineer and we do get out on these jobs, and I think the Health Department knows more about plugging wells than the contractors in the majority of the cases. So be it.

But, Bill, I take exception to plugging sand and gravel wells with sand and gravel. And I'm not a geologist, but I've been associated with geologists, and you know that when nature put the sands and gravels down they were stratified, and your horizontal permeabilities are much greater than your vertical permeabilities. And when you drill a hole through that you destroy it. When you pour sand back in you do not recreate the stratification that was originally there. You do not prohibit the vertical permeability like you get under natural conditions. So we feel that these holes should be plugged with a fine grain size material, a puddled clay or let's say a bentonite type of mixture, rather than going back with the sand and gravel, particularly to keep any surface contaminants from using that as a channel down into a useful aquifer.

Wilbur Whitsell: I'm sure we go along with the finer grain material. We would still prefer that it be filled with something that we can disinfect before we put it down there, and for this very same reason that you mentioned. These materials are stratified, and frequently, despite what the driller reports or what he says, he doesn't really know what he drilled through or hasn't reported it so we don't know. And there can be layers in there that are much more permeable than we realize.

Another part of it would be, in these formations about which we do not have good information, then go the full route and fill it with cement.

Richard Slade: Just for one last clarification. I'm an engineering geologist, not a contractor. My point would be that it's fine to consider backfilling the well with gravel strata, silts, clays, and finer-grained material, until you have a problem that you have a flowing well, first of all. How do you shut those off?

And the second thing, you have a lot of gravel-packed wells. So it actually does no good just to simply pour gravel, or even grout for that matter, because you've got a gravel-packed well. First of all, you've got to consider that you're dealing with wells that were drilled 40 years ago, not 5 years ago.

Wilbur Whitsell: Yeah; let me finish. I've only touched on a part of the well abandonment procedure. One problem—I want to talk about the aquifers. The filling operation, we call the first filling operations would be the aquifer, assuming that is the bottom one, the first one. Assuming we have filled that with an acceptable material, then we must consider the seal which goes above it, which is our way of capping the bottle or sealing it to prevent contaminants from getting in. And this should be done with a cement grout immediately above in the closest impermeable or least permeable formation above the aquifer. We can see 3 types of seals. And whenever we mention seals we are talking about cement grout. Everything else is considered fill. So the first type of cement seal is—I shouldn't say the first one, but one of them—the one that is at the top of the aquifer formation and presumably protects the aquifers from infiltration of contaminants through the bore hole from above.

Another type of seal would be one which you would place between aquifers to prevent the interchange of water between aquifers via the bore hole. And here again, in cases you won't know. If you don't know, then the safest route to go is to go with the cement all the way. In many cases it won't be necessary. We're really wearing suspenders and belts at the same time on some of those things when we do that, because you can prove hydraulically that even with a material of relatively low permeability you cannot generate enough head between these aquifers to cause a significant amount of transfer of water between the formations. We can demonstrate that mathematically. I think you know what I mean there.

Then one other type of seal, cement seal, one other position for the cement seal that we envision is what we call a permanent cement bridge. As you know, you may have cases where you have several hundreds of feet of hole, and there's really no reason for filling all that if you can satisfy your requirements by establishing a seal above. But you need a base for the seal. So we're saying that you may establish a temporary bridge, and there are many ways to do that in well construction, and then pour on top of that the 10 feet—say a minimum of 10 feet of cement, it's called a permanent bridge, and then go with the rest of it.

I think a lot of them will find this attractive, because if you've ever been faced with a problem of having to backfill a well, you've drilled to 150 or 200 feet farther beyond the last aquifer you went through looking for something better and you didn't find it, and then you've got the problem of completing, setting a screen or something in the upper aquifer and you want to backfill all that, that's an awful lot of backfilling. You think you'll never get it done, so you establish a bridge. The only thing that we're specifying is that the bridge—to satisfy anybody who might object to putting organic materials in there—they don't have to be organic materials although we've done it—it should be inorganic materials that are used in that bridge.

Then once you get above the uppermost aquifer and your uppermost cement seal, that zone can be filled with anything which is at least as impermeable as the natural materials around there, up to within 5 feet of the surface. Then we say fill the last 5 feet with whatever you think is the most appropriate for the anticipated use of the land.

The only thing I haven't really covered here is that we recognize that you may have 2 different situations. You may have liners or things in the well that you can't remove. In that case we have written in a couple of requirements for cementing which will improve the cement seal that must be installed within a liner that you can't remove. We recommend you remove everything you possibly can.

Richard Slade: I still want to get back on the fact I still don't feel it's really getting to, say, the gravel-pack quality, by simply filling up a hole, a casing. There's still—the old—we still would have to think in terms of the—

Wilbur Whitsell: Well, you have a gravel pack.

Richard Slade: Pollution is not going to come down through the sand inside the hole, it's going to come down the gravel pack, obviously the most permeable thing in the proximity of the well. And again, going to the fact that a lot of these wells are old, you have a geological record which was made by a driller who probably logged that hole a week after he got home. You mentioned you get very poor geologic data. I just cannot emphasize—I've seen so many hundreds and hundreds of logs that are absolutely worthless—

Wilbur Whitsell: On brand new wells. Brand new wells, just completed and you still don't know what's down there.

Richard Slade: Well, that's true, but that's another problem. But you find these old holes and you have to abandon them, so you pull out the geological log, if it exists first—

Wilbur Whitsell: Right. I know what you're talking about now. The gravel-pack well, California construction, where you gravel-pack all the way to the surface of the ground, even putting some pipes so they can fill it in as they pump sand down there—

Richard Slade: So we've gotten around this by putting in packers, and then squeezing cement against those. We rip the casing above that, and put maybe 10 psi on the pump and squeeze the cement out of there.

Wilbur Whitsell: One of the first things that we have, we started off with it, and the recommendation was that in preparing the well for abandonment, the first thing that you do is remove everything that you possibly can, within reason, to remove whatever they can from the well.

In those particular cases, unless the pipe is cemented in and it probably is not—that particular one you're talking about is not cemented in. They've got it all the way to the top, right? They can cut that casing off at some point. And if they don't want to go all the way to the bottom, there's no reason for them to go all the way to the bottom. Cut it off at the top of the aquifer, remove that casing, let the rest of the gravel pack fall into the well, backfill to there, and then seal from there on up. Would you buy that?

Richard Slade: In the general statement, no, I wouldn't. I'd have to see that well.

Wilbur Whitsell: Well, the thing we're trying to do is to get them to think about what they are trying to do rather than trying to follow a cookbook approach.

Donald Keech: I think we all agree you have to know the construction of the well to be abandoned to design the procedure to be used. And if you don't know, you make the best guess.

Wilbur Whitsell: Then if you don't know, and if you have no way of knowing there's too much down it, then the only route you have to insist on would be cement.

Richard Slade: Unless the well is flowing, I might add.

Wilbur Whitsell: If the well is flowing, then you have to—we've outlined some procedures for getting those under control, too.

Richard Slade: That is getting back to the fact about the people from the Department of Health, and that is they refuse to allow us to put sand in our cement when we're trying to shut off a well that's flowing. As far as we're concerned, it doesn't do much good to put a liquid down the well when you're trying to shut off all the liquid trying to get out of the well. And you've got to reduce your permeabilities. And the only way to reduce permeabilities is to plug up the hole, and that is to get some sand in the cement.

Wilbur Whitsell: Well, anything you put in the cement is going to limit its ability to penetrate.

Richard Slade: We're not talking a saturated solution or anything like that. Small amounts of sand are very effective.

Wilbur Whitsell: Rather than take everybody's time up with this, we have included some recommended procedures for bringing flowing wells under control, and if they would follow those they shouldn't have any trouble. They can seal it with almost anything they want.

Richard Slade: Maybe this is something for NWWA to perhaps work on again. We have drillers who go out and drill holes. We have geologists sometimes, occasionally, if a client has enough money, who will elect to have a geologist sit on his hole and get some good geological data. And a lot of times it ends there with just the geologic logs.

Is there any way that the NWWA can put into their guidelines or specifications or anything of the sort to be of future help, some standards on electric logging water wells? Every time I run a basin-wide survey, study, to try to get water for a client, or this problem we've been dealing with here, abandoning holes without any definite geologic data, it seems that the best data you can possibly have on a well is an electric log. Is there any possible way of looking into that sometime?

Wilbur Whitsell: There are suggested specifications written in there calling for electric logs.

Richard Slade: Government subsidy? I'd like to see it done.

Wilbur Whitsell: I thought there were.

Tom Iwamura: Not in connection with abandonment.

Wilbur Whitsell: Oh, abandonment. Were you talking about abandonment?

Richard Slade: It would apply later to abandonment, at some future time. If you get data collection—

Wilbur Whitsell: During construction?

Richard Slade: At the time of construction. It would serve as a data reference and guide to solve some of the problems of abandonment at a later time, and other problems of water supply, water development in the area. You simply cannot rely on drillers' logs.

James Gentry: Evidently there may be some lack of support from the U.S. Geological Survey in that we don't have any problem in our area of getting electric logs on all formations.

Donald Keech: I am quite familiar with electric logging. One drawback, you cannot electric log the hole once the casing is in place. Thousands, perhaps hundreds of thousands of wells go in with cable tool equipment that would be impossible to electric log. Furthermore, electric logging every well is not practical or feasible.

Wilbur Whitsell: I sympathize with the gentleman's problem that you don't get the logs from the drillers. But those of us who are responsible for the construction of these wells, we've got to assume some responsibility for not getting this information. It has got to be written into the contract. You will sample by certain frequencies and intervals and by certain methods. It's sometimes easier said than done.

Donald Keech: I guess I must speak out in defense of drillers. I can only talk about Michigan drillers. Michigan received in excess of 24,000 drilling records last year. Now I admit that every one of those is not precise. But basically drillers put down an honest record of what their interpretations were. If they are wrong or they're not as professional geologists would do it, then I think that falls on our shoulders to hold education seminars to bring the drillers' ability in that area up where it should be. I think we have made vast improvements in the last 6 or 7 years in Michigan since well records were required.

Wilbur Whitsell: I agree. Most of the blame rests with us in not seeing that they understand what we have to have.

Jim Warman: Let's be very careful that we don't slip into a stance that says that the economist needs to learn how to be a ground-water geologist, or the political scientist needs to learn how to be a ground-water geologist or an engineer, nor the well drillers. We have different roles to play, different kinds of responsibilities. We need to improve our ability to communicate effectively with them to get the job done. Don't ask that well driller to become a full-fledged ground-water geologist and bring all of his training and abilities to bear on these kinds of problems. We need to get in there and better help him, but don't pretend to yourself that you're going to make him totally self-reliant. We're not going to achieve that with many of these people. We have to help them.

Wilbur Whitsell: That's right. I agree a hundred percent. What we want to do is to make sure that he understands the information that we have to have in the way of sampling so we can make these decisions.

Steve Goldstein: Ed Ritchie, you've been engrossed in a lot of this conversation that's been going on, and I think you've got a private one of your own going on in the back. Could you add something, some edification to what's been going on? Give us your version?

Edwin Ritchie, California Department of Water Resources, Sacramento: Can she turn it (the tape recorder) off? (laughter)

We don't know a whole lot about what we are doing yet with abandonment of wells, and all this talk about it, it's a lot of conjecture. We need a lot of experience yet. Does that answer your question? I know the problems that he's faced with, since I'm writing the standards for California. I know the problems he's faced with with the logs. I'm a friend of the drillers—I'm everybody's friend—except once in awhile.

Steve Goldstein: What would you have said had the tape been off? (laughter)

Ed Ritchie: I'm working on the same committee with Bill. So is Ralph over there. It's not easy to write generalizations to cover the specifics, is really the problem. So in any application of standards like these you've still got to use your heads. You still have to either base it on experience or find out the hard way. Somebody spoke in one of the sessions this morning, I think it was in your session, maybe the second or third speaker, said you learn real well by making a lot of mistakes. We've been making mistakes in California now since I wrote the standards 7 years ago. But we're learning a little more.

Things like he talked about, about ripping the casing and trying to get down to that gravel pack by pressure cementing. It's an expensive way to go. We're convinced now that a better way to go, cheaper way, anyway, and almost as effective, is to put grout in and let it go under its own weight. That means if you have a big enough head.

We've had some awful expensive deep structure jobs. I don't know; in my own mind I'm not so sure it's worth it when it costs half as much as the well did. I'm talking about wells that are 700-800 feet deep, 24 inches in diameter, and you want to seal off 2 or 3 different zones. That could be real expensive if you do it the hard way. It could be maybe 5 or 10 percent if you want to try something different. Now, can I edit all that?

Steve Goldstein: I'm going to edit the whole session. I'd be glad to have you do it!

Ed Ritchie: My friend Tom, from Santa Clara Valley, is trying to work on standards that apply to that particular area, with my encouragement.

Tom Iwamura: I'm grateful for all the help.

Steve Goldstein: Gentlemen, is there another line of discussion that anybody would like to pursue?

Jim Warman: I was going to say, I have been on the phone with the Geological Survey of Alabama to secure some specific information about exactly what they do in the evaluation of a site proposed for a sanitary landfill, and I will have that in the Discussion section following my paper.

Steve Goldstein: Thank you, Jim. I thank you all for attending, and invite you to finish what refreshments are left.

Pickling Liquors, Strip Mines, and Ground-Water Pollution[a]

by Wayne A. Pettyjohn[b]

ABSTRACT

In 1964 a waste disposal firm began dumping neutralized spent pickling liquors into an abandoned strip mine in eastern Ohio. In 1970 the disposal pit was enlarged and shortly thereafter significant water pollution problems began to occur. Highly mineralized fluids began to leak from the disposal pit into the surrounding spoil material and eventually into streams and ponds. These solutions are characterized by a low pH and excessive concentrations of dissolved solids, hardness, sulfate, chloride, nitrate, iron, fluoride, aluminum, chromium, nickel, and zinc.

In addition to the contamination by steel mill wastes, acid-mine drainage from surrounding areas degrades both surface and ground water. Acid-mine drainage is characterized by a low pH, and high concentrations of dissolved solids, hardness, sulfate, and iron.

Geohydrologic and geochemical data clearly illustrate that abandoned strip mines should not be used for the storage of toxic liquid or semiliquid materials.

INTRODUCTION

The disposal of acid pickling liquors in a strip mine in eastern Ohio caused serious water pollution problems, fish kills, an irate citizenry, and technical and legal problems for State agencies and industry. The history of the problem is both complex and confusing, largely due to the wide variety and number of groups involved and their expertise and compounded by vested interests, ignorance, and in some cases stupidity. An examination of the situation adequately demonstrates that liquid toxic wastes should not be stored in abandoned strip mines.

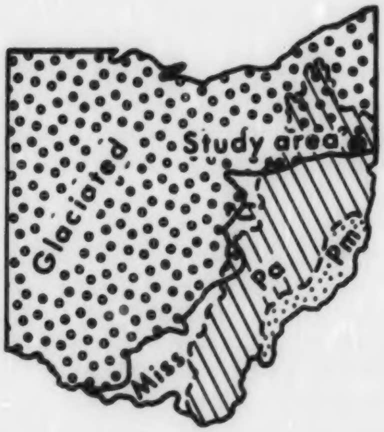

Fig. 1. Generalized geologic map of Ohio and location of study area.

Much of eastern and southeastern Ohio is unglaciated. Rocks forming the gently rolling timber-covered topography consist of eastward-dipping strata of Mississippian, Pennsylvanian, and Permian age (Figure 1). These rocks are composed largely of alternating layers of sandstone, shale, limestone, coal, and underclay.

Coal has been mined in eastern Ohio since 1804. Most of the early workings were underground, but since World War II, production from stripping has exceeded underground removal. In the contour-stripping technique, material overlying a coal seam is removed, starting at the outcrop and proceeding around the hillside. The cut forms a bench and the overburden or spoil is placed on its outer edge. The inside of the bench is bordered by a highwall. Following removal of the coal, successive cuts are made until the depth of overburden becomes too great for economical retrieval of the coal. In many cases, the bench is enclosed by the highwall and spoil ridges. Water collects in these basins forming long, narrow lakes.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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Following the mining operation, stripped lands are of relatively little value due to the rugged highly erodable topography, lack of soil, and commonly acid-mine drainage—the discharge of highly mineralized corrosive water. In view of the low economic value of many of the old strip-mine areas, they have begun to appear as attractive disposal sites for domestic, municipal, and industrial waste. The purpose of this report is to describe some of the effects of waste disposal in an abandoned strip mine.

SITE DESCRIPTION

Large quantities of spent pickling liquors provide significant waste-disposal problems in heavily industrialized areas. Consequently, in the early 1960's a Pennsylvania-based firm proposed to collect and dispose of steel mill acid wastes from throughout a wide area in Pennsylvania and Ohio. The wastes include spent pickling liquors consisting largely of sulfuric and hydrochloric acid and relatively large concentrations of iron, chromium, nickel, manganese, lead, aluminum, and zinc. The firm proposed to mix the pickling liquors with lime (calcium hydroxide), a waste product from acetylene production, raising to 9 or higher the pH of the resulting sludge. The sludge was to be stored in an abandoned strip mine in eastern Ohio.

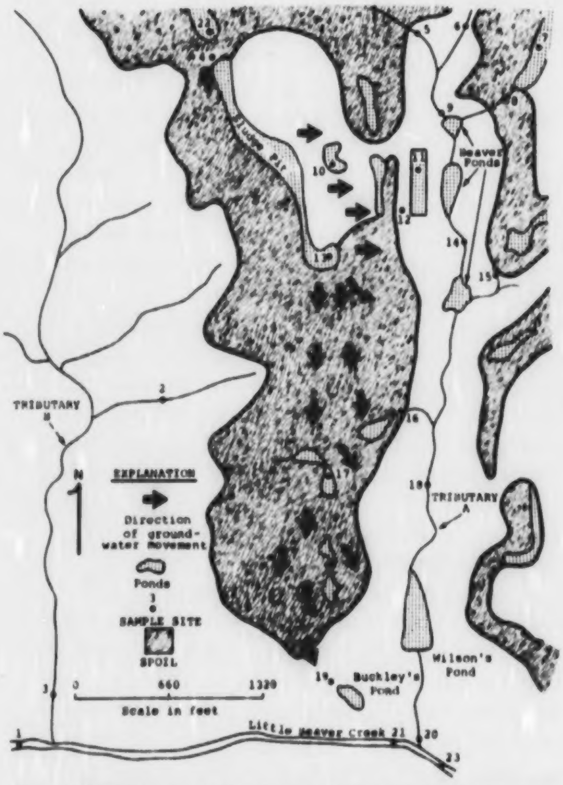

Fig. 2. Sketch map of the disposal area showing location of sampling sites.

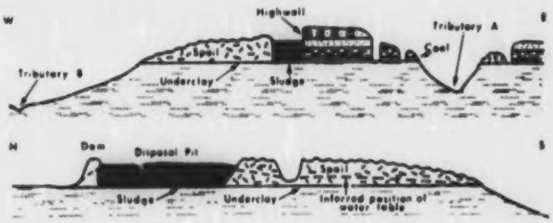

Fig. 3. Generalized east-west and north-south cross sections through disposal and strip-mine area.

The mined area forms a divide between two small streams (Figures 2 and 3). The rocks in this area are typical Pennsylvanian strata consisting of alternating layers of sandstone, shale, coal and underclay. Nearly vertical joints are common in the shale and sandstone. Most of the coal, the No. 6 or Middle Kittanning, was removed by stripping, but very likely there was a small amount of underground or auger mining. Several highwalls and strip-mine lakes occur throughout the area.

The disposal pit is bounded by spoil piles on the west and south, a highwall on the east and an earthen dam on the north (Figure 2). It is about 1700 feet (518 m) long and as much as 200 feet (61 m) wide. The stripped area now covered by spoil materials, extends about 800 feet (244 m) westward from the highwall and southward along a divide for nearly a mile (1.6 km).

A few hundred yards east of the disposal site is a small stream, Tributary A, whose headwaters lie in two long-abandoned strip mine lakes (Figure 2). Tributary A contains three recently abandoned beaver dams and a man-made impoundment (Wilson's Pond). Several other tributaries, all originating in abandoned strip mines, join Tributary A before it flows into Little Beaver Creek, recently designated an Ohio Wilderness Stream. Although Tributary A owes nearly its total flow to runoff from strip mine lands, prior to 1966 it was able to maintain a healthy aquatic life, including beavers, and small-mouth bass in Wilson's Pond.

Lying about a half mile (.8 km) west of the site is Tributary B, whose discharge is more than an order of mganitude greater than Tributary A. Three small streams, a foot or two wide, originate along the western slope of the spoil area and flow into Tributary B (Figure 2).

ORIGINAL SITE EVALUATION

In 1963 the site was examined for the firm by a consulting geologist before a disposal permit was requested from the Ohio Water Pollution Control Board. He reported that there would be no leakage through the 2 to 4 feet (.6-1.2 m) thick underclay which formed the base of the excavation. It was pointed out, however, that some leakage might occur through the overlying sandstone but that it should decrease as the sludge moved into it causing a reduction in permeability. Additionally, concern was expressed over the possibility of fluids leaking through the spoil where this material formed the walls of the potential disposal pit.

The consultant's report and supporting documents were submitted by the firm to the Ohio Division of [the] Geological Survey for examination. This agency informed the Ohio Department of Health that there were no problems with the site and, consequently, a disposal permit was issued by the Ohio Water Pollution Control Board in 1964.

THE PROBLEM APPEARS

The first complaint from local residents was submitted to a State agency in February 1966. Apparently some raw acids were being dumped into the disposal pit, spilled on the ground, and some reportedly were flowing in Tributary A. On March 8, 1966, a second complaint was submitted because cattle refused to drink from Tributary A. A third complaint was initiated in July 1969, because wastes were again being placed in the disposal pit without neutralization. What effect these complaints had on the operation itself or how they may have influenced State regulatory agencies is unknown.

By 1970, the pit was filling rapidly with sludge and in order to provide additional storage space, a narrow section of the pit was widened and deepened, permitting the sludge to flow southward into the low, newly-opened area. Significant water-quality problems began to appear shortly thereafter.

Wilson's Pond, formerly used for fishing, swimming, and boating, became increasingly stressed and a fish kill occurred in the pond in September 1970. Nearly a year later, on August 16, 1971, Wilson's Pond overflowed into Little Beaver Creek causing a major kill that amounted to some 77,000 fish. Following the fish kill, the entire area was examined by the Ohio Department of Natural Resources and water samples were collected from Tributaries A and B, Little Beaver Creek, and from several impoundments. Unfortunately, most of the sample locations were so poorly described that it is impossible to locate the original site within a few hundred yards, or in some cases even a few miles.

After an evaluation of the collected data the Ohio Department of Health ordered the disposal firm to immediately cease the contamination or suspend operation. A short time later, however, the Water Pollution Control Board informed the disposal firm that the Department of Health had no jurisdiction, their order was invalid, and that the operation could continue.

In October 1972, the Ohio Environmental Protection Agency (OEPA) was formed by an act of the legislature. Shortly thereafter the OEPA ordered the disposal firm to close their operation in view of the contamination. The order was appealed and in the spring the office of the Ohio Attorney General took jurisdiction of the case. Following several months of legal involvements between the Attorney General's office and the disposal firm, it was finally agreed, in late fall of 1973, that the company would build a plant and other facilities in order to contain and treat the wastes that were discharging into Tributary A. This agreement is now being carried out, but the firm denied the assertion that they had caused any contamination.

The writer, acting as a consultant for the Attorney General's office, examined the disposal area and collected a series of water samples in 1973. An examination of the chemical and geological data provides an interesting example of the dangers of liquid-waste disposal in strip mines.

SECOND EVALUATION

Sample Collection Sites

On April 14, 1973, water samples were collected from streams, lakes, ponds, springs, wells, and a sludge pit (Table 1) and analyzed at the Ohio Department of Health laboratory. Tributary A was sampled above the sludge pit, along the area of supposed leakage, and downstream from the leakage area. Several small streams feeding into Tributary A were also examined, including those draining from opposite directions into the mainstem

(Figure 2). One strip-mine pond (Site 7) contains an abundance of fish, stocked in past years by the Ohio Department of Natural Resources. The small stream at Site 15 is formed by the leakage of lake water through a spoil bank and although the stream had a pH of 3.4, the lake water is neutral. Site 10 is a small flooded strip mine and an underground working was penetrated by a test hole only a few tens of feet to the south. Site 12 is a spring issuing from a joint and Site 11 is a holding pond used to collect leakage from an abundance of springs and seeps immediately to the west. In order to keep the holding pond from overflowing, fluids are pumped from it uphill to the strip mine pond to the west—a recycling process.

A spoil embankment at the north end of the sludge pit serves as a dam. Site 4 is a small stream, fed by leakage through the dam, which flows into Tributary B where it is rapidly diluted. Site 22 is a shallow strip-mine lake in which some sludge has been dumped. The ponds at Site 17 and adjacent to Site 16 are low spots in the spoil. Site 16 is an overflow stream from the pond and reportedly the west end of the pond does not freeze during the winter suggesting a considerable amount of groundwater discharge. Site 19 is a pipe driven into the hillside that provides water to Buckley's Pond; reportedly the quality of the water in Buckley's Pond has deteriorated significantly since 1971. The immediate area has not been stripped. Sites 21 and 23 are on Little Beaver Creek just upstream and downstream from the confluence with Tributary A. Water samples were also collected from three domestic wells between Buckley's and Wilson's Ponds and another from a well nearly 3 miles (4.8 km) away. Data concerning the other collection sites are shown in Table 1. More than 4 dozen other analyses were also examined during the course of the investigation.

Plant Operation

The largest volume of the pickling liquors received at the site consist of sulfuric and hydrochloric acid with minor amounts of nitric and hydrofluoric acid. Although data are not readily available, the firm reportedly dumped about 725,000 gallons (2,744,125 l) per day in 1972. The acid is neutralized with lime by mixing in large tanks and then allowed to flow by gravity into the pit. The mixed effluent reportedly has a pH of about 11, but two samples show that it ranged between 6 and 12.1 (Table 2). Five cores taken from the sludge in the pit, however, indicate that, with time, the pH tends to decrease. The pH of

Table 1. Description of Sample Collection Sites

Site Number	*Source*	*Location*
1	Stream	Little Beaver Creek upstream from disposed site
2	Stream	Small stream originating at west side of mine
3	Stream	Tributary B below mine
4	Spring	Stream originating as seepage through dirt embankment at north end of sludge pit
5	Stream	Small stream originating at abandoned strip mine
6	Stream	Small stream originating at abandoned strip mine
7	Lake	Lake between high wall and spoil bank
8	Stream	Small stream representing overflow from strip mine lake
9	Stream	Tributary A above sludge pit leakage area
10	Lake	Strip-mine lake
11	Pond	Holding pond used to collect seepage
12	Spring	Water flowing from fracture in shale
13	Sludge pit	Fluid on top of sludge
14	Stream	Tributary A in sludge pit leakage area
15	Stream	Small stream originating from leakage through spoil bank
16	Stream	Overflow stream from "leaky pit"
17	Lake	Lake between spoil banks
18	Stream	Tributary A downstream from major area of seepage from sludge pit
19	Spring	Developed spring that feeds Buckley's Pond
20	Stream	Overflow from Wilson's Pond
21	Stream	Little Beaver Creek above Tributary A
22	Lake	Lake between highwall and spoil bank
23	Stream	Little Beaver Creek downstream from Tributary A

supernatants ranged from 4.4 to 6.2 and the various chemical constituents ranged within wide limits (Table 2).

Furthermore, other core samples show virtually no ferrous iron in solution. It is being precipitated during neutralization. The ferrous iron apparently is being leached both from the sludge in the disposal pit and the spoil material, and moves in the ground water to points of discharge. It is interesting to note that the ferrous iron concentration is practically nil in samples collected in every location except in the area affected by the disposal operation. In all cases the moisture content of the sludge was 70 percent or greater.

As the sludge pours into the pit, it flows first in one direction and then in another as the topography of the sludge surface changes. At the southwesternmost corner of the pit at times there is evident a low circular depression in the sludge surface that probably indicates a point where fluids are rapidly migrating into the adjacent spoil.

A water sample collected in 1972 from a spring along the north wall at the southern end of the pit had a pH of about 4. The spring is several feet above the sludge level in the pit and probably represents acid-mine drainage.

Surface Water

Surface water draining into Tributary A from the north and east originates in strip-mine areas. In many situations, water from coal-mine areas is characterized by high dissolved solids, hardness, sulfate, and iron, and low bicarbonate and pH, but highly mineralized waters are certainly not typical of all such regions. In many parts of Appalachia, municipalities and industries withdraw their water supplies from abandoned or even abandoned parts of working underground mines, and in many cases, the water contains less than 500 mg/l of dissolved solids and is of excellent quality. Acid-mine drainage is more typical of those areas where water seeps through spoil banks removing the soluble products generated by the weathering of iron sulfides.

As indicated by data in Table 3, Sites 5, 6, 7, and 8 contain no more than 377 mg/l of dissolved solids and, although high, the sulfate content is less than Public Health Service recommended limits. Site 15, however, is considerably more mineralized since the entire flow is due to leakage from an adjacent lake through a spoil bank. The water has a low pH (3.4) and high dissolved solids, hardness, and aluminum concentrations.

Water that flows eastward into Tributary A from the north end of the sludge pit to the south end of the spoil pile is highly mineralized, particularly at Site 16. At Sites 12, 16 and 19 the pH did not exceed 3.3, the dissolved solids ranged between 2,250 and 12,200 mg/l, hardness from 1121 to 3770, and sulfate and iron had maximum values of 4760 and 2100 mg/l respectively. These particular constituents and their concentrations are very similar to acid-mine drainage. It is strongly suspected that fluid movement through the spoil accounts for at least part of this unusual occurrence.

On the other hand, the same sample sites, as well as nearby impoundments, contain other

Table 2. Selected Chemical Constituents in Mixed Effluent and Sludge (All Results Except pH and Moisture in Milligrams per Liter)

	Cores from Pit					*Effluent Before Dumping*		
	1	*2*	*3*	*4*	*5*	*1*	*2*	*3*
pH	5.9	6.1	6.2	5.8	4.4	10.9	6.0	12.1
Cl	2700	3050	3450	5200	8000	510	–	–
F	5.9	3.55	4.0	5.05	9.5	1.98	–	–
Cd	0	0	0	.09	.08	–	.06	–
Cr	0	0	0	.07	.04	.32	1.5	–
Fe	94	23.8	13	100	4500	27	1250	–
Pb	.18	.20	.23	.35	.23	0	.6	–
Ni	.10	.20	.23	.81	3.8	.6	.6	–
Zn	6.6	2.5	.72	3.0	180	.1	1.23	–
Hardness	–	–	–	–	–	13100	–	–
Dissolved solids	–	–	–	–	–	26600	–	–
NO_3	–	–	–	–	–	3400	–	–
SO_4	–	–	–	–	–	978	–	–
Moisture (percent)	70	70	80	–	80	–	–	81.7

Table 3. Concentration of Selected Constituents from 23 Sites in the Vicinity of Little Beaver Creek, Ohio (All Results Except pH in Milligrams per Liter)

Site No.	*pH*	*Dissolved Solids*	*Hardness*	*NO_3*	*SO_4*	*Cl*	*F*	*Al*	*Cr*	*Fe*	*Ni*	*Zn*	*Mn*
1	7.2	328	142	2	85	11	.14	.4	0	.6	0	0	.12
2	7.0	1050	704	0	266	0	.23	.9	0	1.3	0	0	.17
3	6.7	477	226	1.4	143	11	.33	.8	.01	1.6	0	0	.35
4	3.0	14500	–	740	4110	1000	1.76	265	3.05	220	36	48	272.
5	6.5	337	198	0	180	0	.23	.1	0	.2	0	0	.68
6	6.4	377	242	.9	192	3	.13	.3	0	.6	0	0	.67
7	7.1	182	104	–	76	4	.16	.1	0	.2	0	0	.06
8	6.2	174	102	1.6	65	1	.12	0	0	.1	0	0	.02
9	6.9	510[1]	–	–	190	6	–	–	–	.8	0	0	–
10	4.9	2250	1000	9.6	714	300	.7	.1	.01	76	.2	.2	7.24
11	3.8	2220	1100	1.5	828	300	.45	5.4	.01	10.8	.3	.2	11.35
12	3.3	2250	1121	–	881	430	.31	4.0	.01	36	.1	.2	7.26
13	9.6	6550	2800	220	1890	900	4.6	30	2.5	280	2	3	2.60
14	6.6	484	280	.9	219	4	.15	1.6	.01	7.6	0	0	1.58
15	3.4	1140	388	.4	599	1	.61	11.4	0	.9	.5	.7	7.32
16	3.2	12200	3670	340	4760	750	1.5	100	.07	2100	18	58	145.
17	3.1	11400	2800	320	4160	750	1.9	66	.06	1950	16	40	116.
18	3.2	2250	1000	54	903	200	2.5	15.6	.02	320	2.5	8.8	27.5
19	3.3	3630	2620	51	2000	290	3.4	38	.01	14.1	1.9	8.4	59.2
20	3.0	–	–	–	841	240	–	–	–	220	2	7.1	–
21	7.5	250	142	2.1	80	12	.13	.5	0	.8	0	0	.26
22	6.9	–	514	5.0	533	119	1.37	.3	0	1.0	.01	.3	2.38
23	6.0	355	220	8.4	207	35	.8	1.9	0	35	.3	1.1	3.60
PHS[2]	6-8.5	500	300-600	45	250	250	1.7	–	.05	.3	–	5.0	.05

[1] Conductivity

[2] Public Health Service recommended limits for drinking water

substances in high concentrations that are totally dissimilar to acid-mine drainage. These include nitrate, chloride, fluoride, chromium, nickel, and zinc, which are more indicative of contamination by pickling liquors.

Small streams along the west side of the spoil area flow into Tributary B. Although at Site 2 the sulfate concentration was 566 mg/l, the pH was 7 and the other constituents were well within expected limits. At Site 3, Tributary B, however, does reflect the higher sulfate concentration of the tributaries derived from acid-mine drainage.

Even a brief examination of the data in Table 3 indicates that Tributary A is grossly contaminated and that the major source is the adjacent sludge pit and spoil material to the west. The reasons Tributary A is grossly contaminated relatively to Tributary B are (1) the steeper hydraulic gradient toward Tributary A, (2) an abundance of large joints in the sandstone and shale between the sludge pit and the tributary, (3) some spillage in past years of sludge or untreated acids directly into the stream, and perhaps most significantly, (4) the presence of underground workings between the sludge pit and Tributary A. One such opening probably extends from the sludge pit to the impoundment adjacent to Site 16.

The chloride ion was an especially good tracer in the study, in spite of the fact that the firm suggested that a possible source of the high chloride concentration was leakage through abandoned oil wells, several of which exist in the area. There are no records indicating that any oil wells were ever drilled in the strip-mine area, but similar State agency files also indicate that there are no underground workings in the area either!

Ground Water

There are two major sources of the water that discharges from the spoil surrounding the disposal site: (1) fluids squeezed from the sludge during compaction, and (2) infiltration of precipitation throughout the spoil area. These fluids tend to become even more highly mineralized as they flow through the spoil to points of discharge. It is also suspected that there are significant geochemical changes occurring in the sludge leading to the generation of low pH fluids.

As the waste fluids migrate east and south through the spoil, the low pH tends to maintain or perhaps even increase the concentration of heavy metals in solution. There is probably little chance for dilution or even dispersion, particularly in view of the steep gradient and flow through underground openings.

Data from several test holes drilled around the southeastern extremity of the sludge pit tend to complicate even more an understanding of the situation (Table 4). The uncased test holes ranged in depth from 40 to 95 feet (12 to 27 m) and the pH of water withdrawn from them ranged from 3.86 to 7.40. Although drillers' logs and other data concerning water levels, methods of collection, and time intervals are not available, at least some of the holes were drilled to depths near the elevation of the bottom of the sludge pit. The data indicate, however, that the ground water in the area of the test holes is not as grossly contaminated as that at Sites 12, 16, 17, and 19.

Other than the above-mentioned test holes, wells have not been drilled in the spoil area or adjacent unmined regions, but in view of the contaminated springs and seeps that surround the area, there is little doubt but that the ground water is highly mineralized. In addition to the abundance of springs along the eastern and southern margins of the spoil, the topography, elevation of the water surface in lakes, and the water quality all indicate that the general direction of ground-water movement is to the south and southeast.

Table 4. Data from Test Holes Adjacent to the Sludge Pit

Test Hole No.	*Depth*	*pH*	*Total Fe (mg/l)*	*Ferrous Fe (mg/l)*
1	68-70	4.17		
	90-95	4.04		
2	70	4.23		
3	Dry			
4	Dry			
5	76.77	7.40	111	103
6	52	3.86	–	24
	95	5.29	–	25
7	80	6.01	1440	1430
8	65	4.11	–	25
	95	5.42	1550	1240
9	65	4.33	1390	1280
10	68	4.33	–	34
	95	4.03	–	33
11 (Underground working)	40	5.72	64	55
12	40-42	6.77	140	90

Table 5. Selected Chemical Constituents in Domestic Well Water Supplies (All Results Except Conductivity and pH in Milligrams per Liter)

Constituent	*1*	*2*	*3*	*4*[1]
Conductivity	550	490	320	400[2]
pH	7.9	7.5	8.2	7.4
Hardness	70	106	50	200
NO_3	.1	.1	.33	2.3
SO_4	Tr	Tr	–	33
Cl	2	0	1.0	29
F	.41	.39	.72	.13
Fe	–	.9	0	0
Ni	0	0	0	0
Zn	0	.6	–	.4

[1] Well is 2.8 miles east of disposal site

[2] Dissolved solids

Several homes and a school lie along a road paralleling Little Beaver Creek from Wilson's Pond to Tributary B. Their water supplies are all obtained from wells a few tens of feet deep. Samples were collected from three of these wells (between Wilson's and Buckley's Ponds) in April 1973, but as yet none have been contaminated. Analyses of these waters and a fourth well about 3 miles (4.8 km) to the east are shown in Table 5. There is a strong possibility that these wells could become contaminated, particularly in view of the situation at Site 19.

CONCLUSION

Although a treatment plant and pumping facilities are scheduled for construction, probably in the vicinity of Site 18, this will not entirely solve the problem. Some means must be devised to intercept or divert the southward flowing ground water in the vicinity of Site 17. It may well be years before the water-quality problem is under control. Of course, none of these problems would ever have come into existence if an abandoned strip mine had not been used for waste disposal.

DISCUSSION

The following question was answered by Wayne A. Pettyjohn after delivering his talk entitled "Pickling Liquors, Strip Mines, and Ground-Water Pollution."

Q. by K. Bradley. *Why didn't the lake below the strip-mine site freeze over? Is there any time limit to the neutralization-precipitation, etc.?*

A. The lake didn't freeze largely because ground water was rapidly discharging into it. I suspect the ground water was flowing through an underground opening, probably an auger hole, that terminated in collapsed spoil material adjacent to the west end of the lake. I don't understand the second question.

Effluent for Irrigation — A Need for Caution?[a]

by William H. Walker[b]

ABSTRACT

Most municipal waste treatment systems receive, treat, and eventually discard to some segment of the environment storm runoff and liquid wastes from all industrial, commercial, and domestic areas and establishments in the community. At any given time these wastes may contain viruses, antibiotics, hormones, nutrients, weedkillers, fungicides, pesticides, trace metals, and an almost countless number of toxic chemical compounds. Present treatment by the old, ineffectual sewage treatment methods and facilities still employed generally does not remove nor reduce to a harmless state all of the hazardous materials contained in the waste streams entering the plant. Some are more concentrated when they leave the plant in effluent and sludge than they were upon entry.

Existing pollution protection laws prohibit surface-water dilution of these effluents and sludges. Drying, burning, or distilling them is very costly, causes air pollution, and produces potentially hazardous chemical residues which still must be disposed of in some nonpolluting fashion. There are no "technologically feasible, economically reasonable" alternative methods of effectively treating these wastes to an acceptable quality level for discharge to streams. For these reasons, land disposal of sewage effluent and sludges now is being widely promoted and employed as the best available method of treatment.

It is estimated that as many as 300 municipalities have gone to the land to solve their sewage plant waste problems in recent months. Many of these have been at least partially funded with State and Federal grants. If similar permits and financial assistance continue to be granted in the future, it is anticipated that several thousand municipalities will follow suit within the next few years.

Most operating facilities for land disposal of effluents are not monitored adequately to provide required data to quantitatively evaluate the total buildup and possible subsequent release of toxic chemicals in contiguous soil, plant, and water environments. Considering the potential danger to public health which may result if widespread use of this particular waste disposal practice is employed, it is imperative that all such permitted sites be monitored and evaluated in detail for all possible adverse effects, and the results of these findings then considered in the design and operation of future installations, if minimal pollution from this practice is to be assured in the future. Concurrent with this work, research must be expedited and greatly expanded to develop effective alternative treatment methods to employ where land disposal of effluent proves to be impracticable.

INTRODUCTION

Practically all municipal sewage treatment facilities now in use employ a method of treatment which was designed for another time when wastes were mostly of domestic origin, consisting of only a few known harmful bacteria and a small quantity of settleable organic solids. Treatment of such waste material was relatively simple: solid-liquid separation; bacterial treatment under anaerobic conditions to kill oxygen-dependent bacteria; aerobic-filtration treatment to remove solids and to kill anaerobic bacteria; and final discharge to some nearby water course for additional dilution. At that time our population was largely rural with less than 15 percent of the people living in urban areas. Now, less than 5 percent of the population live in rural areas; the remainder are living, working and polluting in metropolitan areas constituting less than 10 percent of our total land area.

The wastes formerly produced also have changed in an equally drastic fashion. Steam engines, candles, and coal-wood energy sources have been replaced by internal combustion and jet engines, electricity, hydrocarbons, and atomic energy sources. Outside privies were abandoned long ago for indoor flush toilets, and wooden washtubs gave way to automatic washing machines, dishwashers, and bathrooms supplied with hot and cold running water. All of these replacements require a much larger quantity of water and produce a resultant waste-liquid volume much larger than before. Biodegradable animal-fat and vegetable-oil soaps were mostly forced from the market by relatively nondegradable detergents containing large concentrations of inorganic chemicals like phosphate. So was smelly, messy-to-handle, animal-waste fertilizer formerly used on city lawns and gardens and nearby farmlands, because of readily available inorganic nitrogen and other plant nutrients that smell better and are easier to handle and use. Industries largely oriented toward the processing of farm-produced organic materials now have been joined by others which manufacture or process new kinds of metal and petrochemical products that were practically nonexistent 50 or so years ago.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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Hazardous chemical, biological, and virological contaminants from industry, hospitals, and educational-commercial laboratories scattered in and around most towns now are normally diverted to the municipal sewage treatment facilities for processing along with the storm runoff and sanitary sewage flow from throughout the community.

Included industrial chemical wastes may contain acids, alkalies, chlorinated hydrocarbons, all kinds of toxic metals, and a multitude of hazardous chemical compounds. Added to these from the general community might be appreciable quantities of inorganic fertilizer and pesticide-rich runoff from residential yards; zinc and copper from water-system piping and plumbing fixtures; lead, cadmium, cyanide, chlorides, and hydrocarbons from city streets; nutrients as well as all kinds of chemicals used for cleaning, maintaining, and beautifying modern-day households; and perhaps even prohibitive concentrations of mercury derived from such commonly used products as paper towels and toilet or facial tissue.

Many of the hazardous wastes apt to be present in sewage plant discharge streams are costly to analyze and to evaluate quantitatively by presently available equipment and methodology. Because of this they are not identified in typically prescribed waste-stream analysis programs, an omission that creates continuous uncertainty concerning their possible existence and concentrations in sewage-plant effluent and sludges. In addition, for most of these, no definite human-animal-plant tolerance levels have been established.

It is this type of liquid and semiliquid waste material from municipal sewage treatment plants situated throughout the United States that is now being dumped on the land.

PRIMARY CONTROLLING FACTORS

In our society, many different conflicting philosophies concerning waste disposal prevail among various segments of the scientific and industrial communities, environmentalists, the general public, and governmental control agencies. Most of the controversy and resultant arguments concerning this subject generally fall into three different yet interconnected broad avenues of concern and specialty—legal, economic, and technical. The complexities of the over-all problem are immense when viewed from any one of these vantage points; interdisciplinary attempts of definition, evaluation, and regulation present almost innumerable complications. The following statement taken from one State's Pollution Control Board Regulations generally epitomizes the prevailing state of confusion and illustrates all too well the difficulty invariably encountered when an attempt is made to develop a meaningful, positive, and enforceable regulation on the subject.

> "Pollution control facilities must afford the best practicable degree of wastewater treatment or control consistent with technological feasibility, economic reasonableness, and sound engineering judgement."

If practical long-term pollution control is ever to be realized within the framework of such a vague, all-encompassing decree, much interdisciplinary action and cooperation will be required, particularly between the legal, economic, and engineering fields of specialty. The following subjects appear to be in need of their special coordinated action.

LEGAL CONSIDERATIONS

Air and surface-water pollution protection laws which force an ever-increasing quantity of hazardous waste to the land for ultimate disposal must be changed drastically, and soon, if optimum environmental pollution protection is to be assured. All new laws developed and finally adopted must be a part of an over-all environmental pollution protection act which permits and forces all major pollution dissipation regimes (air, surface water, ground water, soil, and vegetation) to share to their full capability their proportionate part of the burden of total pollutant transport, containment, and dissipation. No longer can we continue to solve pollution problems in one dissipation regime in such a fashion that an even more serious and hazardous problem may be created in some other equally important ecosystem. If laws are to ensure protection of the air and surface water, so must they also equally protect the ground water, soil, and plant regimes. At the present time, these are being placed in serious jeopardy by existing air and surface-water protection regulations.

Hazardous chemical waste materials such as chlorinated hydrocarbons can be disposed of far more safely by incineration under high-temperature controlled-burning procedures than could ever be realized by surface-water or land-ground-water disposal. By the same token, trace concentrations of many of the toxic metals, and such common salt pollutants as nitrate, chloride, and sulfate, can best be reduced to harmless levels by dilution in large volumes of surface-water flow. Chemical reconstitution of some pollutants to an inert, relatively insoluble form, encapsulation in an impermeable container or polymer for later recovery, and chemical separation-recycling are equally viable alternative disposal methods which must be covered by the law if optimum pollution abatement and control at minimum cost are to be assured. Heavily industrialized countries in Europe are presently employing all of these ways and means of hazardous waste disposal. A study of their methodology, procedures, and results should be immediately initiated so that the best of their findings may be incorporated in revisions of our own technology, laws, and regulations.

Also, it is essential that all new pollution protection laws passed reflect the legal philosophy that poisonous chemicals and other wastes known to be harmful to public health must be considered guilty until proved innocent instead of innocent until proved guilty as is now so widely accepted. Only in this way can the burden of proof of a pollutant's guilt or innocence be rightfully placed upon the polluter, not upon affected society as is now the case under existing laws. This new approach in law should encourage hazardous pollutant volume reduction and subsequent pollution abatement from such sources. However, if it fails to do so, volume reduction of the more hazardous pollutants may have to be dictated by imposing true-cost disposal assessments on the manufacturer-user, and/or placing legal constraints upon the total quantities manufactured. By the same token, hazardous chemical wastes from industries, biological-virological contaminated sewage from hospitals, and chemically contaminated runoff from streets, parking lots, and factory grounds now dumped into sanitary or interconnected storm sewers may reduce the quality of municipal plant effluents to something less than desirable or even permissible for disposal on the land. For this reason, any laws passed also must reflect consideration of these adverse factors by encouraging, or even forcing where necessary, separation of industrial and storm runoff streams from the old sewage treatment facilities which were primarily designed for the processing of domestic-type wastes.

ECONOMIC CONSIDERATIONS

When considering the economics of pollution, one is immediately faced with the harsh realization that the actual cost of pollution is generally undefined, particularly in the areas of adverse effects to public health, and in the true treatment costs to other, downstream users. These answers are needed now so that the initial sales price of every pollutant can be made to include the total costs of all required control measures. Only in this way can the people who make, distribute, and use a pollutant be properly assessed for the beneficial values they receive from its use. Other factors involving actual cost that are often ignored in our present approach to the problem are:

1. A pollutant is a valuable resource out of place.

2. Pollution from any source will continue only for so long as it remains more economical to permit it to occur than to stop it.

3. For every one who profits from polluting there are many others who may incur losses from such action.

All of these suggest that recycling, or separation-concentration-storage of potentially hazardous wastes until reuse is economically feasible, may be the optimum solution to most of our pollution problems. However, the economical and legal ramifications of such solutions are not now definable because of inadequate prerequisite technological knowledge and input.

TECHNICAL CONSIDERATIONS

Generally expressed justification for using the land for waste disposal is based on the hypothesis that earth materials have the capability to precipitate, adsorb, absorb, exchange, convert, decompose or volatilize all kinds of hazardous material to a harmless state. However, land disposal practices conceivably could become a very dangerous and costly mistake if the soil and associated ecosystems prove to be only a partial or temporary filtration-retention-removal unit as is suggested by an ever-increasing number of air, vegetation, and water pollution occurrences. That the land's "living filter" capability is finite, and at best capable of only temporarily retaining many of the hazardous chemical pollutants it must now receive under prevailing environmental protection policies and laws, is seemingly adequately proved by the case studies illustrated in the few select references included in this paper. However, even if these are too few, surely the many hundreds of other similar adverse-effect case histories recorded in technical publications from throughout the world would provide sufficient proof if all of these were combined in one publication and made readily available for use by legal-regulatory authorities everywhere.

Although several hundred systems for land disposal of sewage effluent and sludge have been in operation for a number of years, nearly all of them are equipped with only minimal and generally ineffectual monitoring systems which seldom are capable of detecting even excessive surface-water and ground-water pollution from the sites. Monitoring data obtained from these systems are practically useless in quantitatively evaluating the total toxic chemical buildups in contiguous soil, plant, and water environments, or in defining the vertical and horizontal migration patterns of pollutants through underlying earth materials. Without such answers it is impossible to truly appraise the validity of this land disposal method. However, as the method is seemingly the only "economical" one still available for use, in all probability it will continue to be permitted, perhaps at even a more expedited pace than now, until or unless it is conclusively proved that this method is ineffective in removing hazardous pollutants from the environment. Just how long such proof accumulation and acceptance will require is not known. However, considering the minimal number of researchers now engaged in this work, the acutely low level of research funding available, the mounting pressures from municipalities and industries for permission to dispose of their liquid waste material in this fashion, and the millions of dollars now being expended for development and operation of such sites, it seems likely that several years will pass before any other disposal methods are seriously considered or employed.

Many promising new methods of treating modern-day municipal sewage have been discussed and described in articles and papers scattered throughout the world's technical publications and scientific journals. All of these should be assembled and evaluated from an effectiveness-economic standpoint. At the same time, research must be expedited and greatly expanded to discover and perfect additional methods of waste treatment-separation-elimination. Also, much more in-depth research must be conducted on the optimum nutrient needs of all the various types of plants, and the time, quantity, and chemical makeup of sewage effluent or sludge to apply for maximum plant growth and minimal environmental pollution under all soil and climatic conditions which prevail throughout the country.

Until all of these essential scientific inputs are available, only a minimal number of new effluent irrigation disposal installations should be permitted.

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DISCUSSION

The following questions were answered by William H. Walker after delivering his talk entitled "Effluent for Irrigation — A Need for Caution?"

Q. by R. G. Kazmann. *Do you think that we ought to use our rivers to remove biodegradable material and just try to eliminate poisons, heavy metals, fluorocarbons, etc.?*

A. An all-encompassing environmental pollution protection law is critically needed, a law which permits and forces all major pollution dissipation regimes (air, surface water, ground water, soil and vegetation) to share to their full capability their proportionate part of the burden of total pollutant transport, containment, and dissipation.

Hazardous chemical waste materials such as chlorinated hydrocarbons can be disposed of far more safely by incineration under high-temperature controlled-burning procedures than could ever be realized by surface water or land-ground-water disposal. By the same token, trace concentrations of many of the toxic metals, and such common salt pollutants as nitrate, chloride, and sulfate, can best be reduced to harmless levels by dilution in large volumes of surface-water flow. Chemical reconstitution of some pollutants to an inert, relatively insoluble form, encapsulation in an impermeable container or polymer for later recovery, and chemical separation-recycling are equally viable alternative disposal methods which must be covered by the law if optimum pollution abatement and control at minimum cost are to be assured. Heavily industrialized countries in Europe are presently employing all of these ways and means of hazardous waste disposal. A study of their methodology, procedures, and results should be immediately initiated so that the best of their findings may be incorporated in revisions of our own technology, laws, and regulations.

Q. by Rein Laak. *Is there no denitrification in natural nitrogen cycle?*

A. Surely there is *some* denitrification in the natural nitrogen cycle. But how much? And how does this quantity vary with different soil types, or varying climatic, temperature, and carbon-availability condition? For example, in a ground-water nitrate pollution study we made in 1971-72 in southwestern Illinois in the late fall after crops had been harvested, we found that 186 pounds of nitrate nitrogen (NO_3-N) per acre were contained in the upper 12 inches of soil in a cornfield where 100 bushels of corn had just been gathered. The farmer had only applied 125 pounds NO_3-N at the beginning of the growing season. The available nitrogen remaining after the growing season ended could only be attributed to *nitrification* of past years plowed under plant residue left in the field. Following our detection of this accumulation we sampled this field two more times during the winter, when the ground was semifrozen, and soil temperatures to the 18-inch level were below 35 degrees F (at times when denitrification losses should have been minimal), and discovered that *all* of the nitrogen formerly present in the upper 12 inches in October was transported by precipitation recharge to the ground-water reservoir before the next growing season began.

Later on, we brought samples of this soil back to our laboratories and attempted to induce denitrification under controlled conditions. We could not induce significant denitrification to occur at temperature ranges normally found in the soils and ground-water reservoir of that area even after adding carbon to make up for the gross lack of that constituent within the soils at depth at that location. At higher temperatures we did realize significant denitrification under the latter conditions, but this we considered more an academic exercise than a practical, meaningful result.

Dr. A. M. Buswell, formerly Chief of the Illinois State Water Survey and Head of our Chemistry Section, stated in Water Survey Bulletin No. 26 in 1924, "From a survey of the literature on this question, there are no data in the literature showing that nitrogen gas is formed to any great extent during the reactions of sewage purification." Since that time other scientists have published data showing that denitrification does occur under special conditions and circumstances and many rules of thumb values now are widely used and applied for this phenomenon even though those often using these values haven't the vaguest idea as to where they came from, under what conditions they apply, and whether or not they apply in the case of soil-ground-water conditions. In fact, to my knowledge no indisputable, factual data ever has been published to prove that significant denitrification occurs after nitrogen-rich water reaches the water table. Instead, all of the reports I have seen which infer that denitrification must have occurred because little nitrogen was found in the ground water during their study almost invariably had made only token effort or expenditures to actually define the *total* nitrogen content of the *entire* effective zone of saturation. This is not surprising because their primary investigative tool was observation wells, generally placed at shallow "cheap" depths and never enough to positively prove they had truly sampled all vertical segments of all existing permeable zones which might have been transporting the nitrogen-rich water.

Much research is needed in this particular area—research for the humid regions of the country as well as the arid parts where much of the past work on this subject has been done in the past. In the meantime, I personally assume that denitrification losses are minimal in most soil types and ground-water conditions prevalent in Illinois, and that instead most of the unaccounted for nitrogen escapes undetected to underlying ground-water reservoirs.

Chemical Interaction During Deep Well Recharge, Bay Park, New York[a]

by Stephen E. Ragone and John Vecchioli[b]

ABSTRACT

The U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, recharged tertiary-treated sewage (reclaimed water) into the Magothy aquifer in 13 recharge experiments between 1968 and 1973. The recharge resulted in a degradation in water quality with respect to iron concentration and pH. Iron concentration increased from the range 0.14 to 0.30 milligrams per litre to as much as 3 milligrams per litre at the 20-, 100-, and 200-foot or 6.1-, 30-, and 61-metre observation wells as the reclaimed water displaced native water. The increase was presumably a result of pyrite dissolution. The pH of the water decreased from the range 5.22 to 5.72 to a low of about 4.50, predominantly as a result of cation-exchange reactions.

INTRODUCTION

Population in Nassau County, an area adjacent to New York City on Long Island, New York, increased from 0.41 million in 1940 to 1.43 million in 1970 and is expected to increase to more than 1.63 million by the year 2000 (Scope of Public Water-Supply Needs, 1972). Pumpage from ground water, the only source of public supply in 1974, increased from 75 m gal/d (million gallons per day) or 3.29 m^3/s (cubic metres per second) in 1940 to 215 m gal/d (9.42 m^3/s) in 1970. Pumpage is expected to be within the range of 258 and 313 m gal/d (11.3 and 13.7 m^3/s) by the year 2000 (Scope of Public Water-Supply Needs, 1972). The increased demand for water and a decrease in recharge resulting from the replacement of cesspools with sewer systems that discharge into offshore bodies of water will probably cause a water deficit between 93.5 and 123 m gal/d (4.10 to 5.39 m^3/s) in Nassau County by the year 2000 (Scope of Public Water-Supply Needs, 1972).

In 1968 the U.S. Geological Survey, in cooperation with the Nassau County Department of Public Works, began an experimental, deep-well, recharge program at Bay Park (Figure 1) to study the feasibility of recharging tertiary-treated sewage (reclaimed water) into the Magothy aquifer. Reclaimed water was recharged in 13 experiments and city water in 6 experiments between 1968 and 1973. Two adverse effects of recharge with

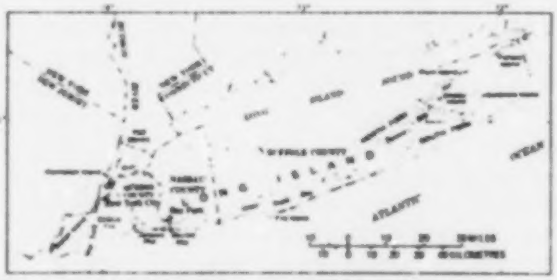

Fig. 1. Location of recharge site, Bay Park, New York.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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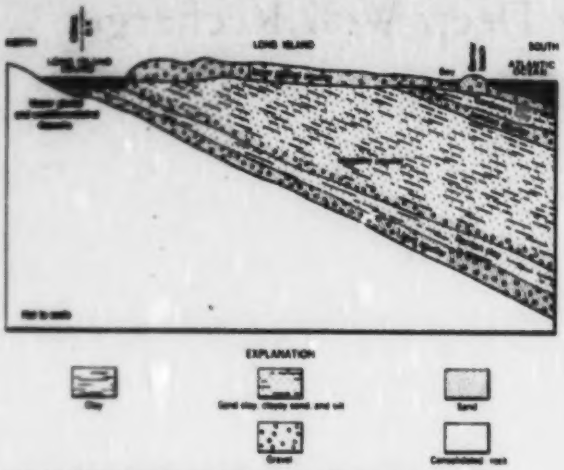

Fig. 2. Major hydrogeologic units of the ground-water reservoir of Long Island, New York.

reclaimed water—an increase in iron concentration beyond the standards for drinking water set by the U.S. Public Health Service [1962 (standards to which drinking water and water-supply systems used by carriers and others subject to Federal quarantine regulations must conform)] and an increase in acidity—and attempts to relate these effects to the geochemistry of the reclaimed water-native water system are described in this report. Most of the data were collected during the 13th experiment with reclaimed water in which 41.7 million gallons of the water were recharged intermittently over a 6-month period.

HYDROGEOLOGY

The Long Island ground-water reservoir consists of a wedge-shaped mass of unconsolidated Pleistocene glacial deposits and underlying Cretaceous fluvial and deltaic deposits (Figure 2). At Bay Park, thickness of the unconsolidated deposits is estimated to be 1,250 ft (381 m) (Vecchioli and others, 1974).

The recharge well at Bay Park is screened in the Magothy aquifer, a mostly gray, very fine to medium sand that contains some silt and clay layers. X-ray analysis of a sample taken at a depth of 527 ft (161 m) at the recharge site indicated that the clay is composed of equal parts of kaolinite and illite. Lignite occurs as disseminated particles or layers. Pyrite and marcasite are also present and commonly occur in association with lignite. Other accessory minerals include muscovite and trace amounts of tourmaline, garnet, zircon, andalusite, and sillimanite (Vecchioli and others, 1974).

The recharge zone is semiconfined by other Magothy beds of lower hydraulic conductivity. Static water level of this zone is about 5 ft (1.5 m) below land surface.

WATER RECLAMATION AND RECHARGE FACILITIES

About 1 percent of the effluent from the Bay Park secondary sewage-treatment plant is diverted to a 400-gal/min (gallons per minute) or 25-l/s (litres per second), demonstration, tertiary-treatment plant where the effluent receives physical-chemical treatment. The product of the tertiary-treatment plant, reclaimed water, meets potable-water standards (Peters and Rose, 1968). The reclaimed water is pumped about 0.5 mile (0.8 km) to the recharge site. Detailed descriptions concerning design and operation of the recharge facility have been published (Koch and others, 1973; Perlmutter and others, 1968; Cohen and Durfor, 1966 and 1967), so only a brief description is given here.

The facility consists of: (1) a 50,000-gal (gallon) or 189,000-l (litre) storage tank, (2) an 18-inch- (46-cm-) diameter fiberglass recharge well with a 16-inch- (41-cm-) diameter by 62-ft- (19-m-) length stainless steel screen at a depth of 418 to 480 ft (127 to 146 m), (3) various equipment for further treating the reclaimed water or city water (dechlorination, degasification, Eh/pH adjustments), and (4) 18 observation wells at distances from the recharge well ranging from several inches to 200 ft (61 m) and screened at various depths ranging from several feet to more than 700 ft (213 m) below land surface.

Most of the water-quality data collected during the recharge experiments were obtained on samples from observation wells screened within the zone of recharge (418 to 480 ft or 127 to 146 m below land surface). These wells are designated N7886, N7890, and N8022. Wells N7886 and N7890 are 20 ft (6 m) and 100 ft (30 m), respectively, southwest of the recharge well. Well N8022 is 200 ft (61 m) northeast of the recharge well.

The recharge well and the observation wells were constructed of nonferrous or noncorrodible materials to minimize any possibility of chemical reaction with either the native water or the reclaimed water.

CHEMISTRY OF NATIVE AND RECLAIMED WATER

Water samples for chemical analyses were collected from the observation wells before the recharge experiments were started and before,

Table 1. Pertinent Chemical and Physical Data of Native and Reclaimed Water
(All data in milligrams per litre unless otherwise indicated)

	Native water[1]	*Reclaimed water*[2]	
	Range	*Mean*	*Standard deviation*
Silica (SiO_2)	7.2 – 7.4	13	1
Iron (Fe), total[3] µg/l	140 –300	410	260
Iron (Fe), dissolved[3] µg/l	140 –300	230	180
Manganese (Mn), total µg/l	30	75	31
Calcium (Ca)	.4 – 1.4	20	3
Magnesium (Mg)	.2	6.4	2.1
Sodium (Na)	3.7 – 3.9	86	12
Potassium (K)	.4 – .6	13	1
Bicarbonate (HCO_3)[3]	4.5 – 7.5	59	19
Sulfate (SO_4)	3.6 – 4.0	160	20
Chloride (Cl)	3.9	99	23
Nitrogen, ammonia, total as NH_4	.8 – .9[4]	30	2
Dissolved solids, residue at 180°C	22 – 25	398	68
Specific conductance,[3] (micromhos/cm at 25°C)	28 – 32	786	81
pH[3]	5.22– 5.72	6.1[5]	.2
Water temperature, °C[3]	15	17.5	2.0
Oxidation reduction potential (Eh, in volts)[3]	–.03– –.10	N.D.	–
Dissolved oxygen (DO)[3]	0	4.5	1.6
Chemical oxygen demand (COD) 0.025N $K_2Cr_2O_7$	0	9	5

[1] After Vecchioli and others, (1974), for samples taken from the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) observation wells before any recharge, unless otherwise stated.

[2] Based on the weighted average of at least 33 daily or weekly composite samples.

[3] Field data.

[4] Data from RW10 (reclaimed-water test 10).

[5] Mean calculated after converting pH values from logarithmic form to exponential form.

during, and after individual recharge experiments. The samples were obtained with either submersible or suction pumps and, on occasion, with a Foerst sampler. Samples of reclaimed water were collected during the recharge tests at the point of injection and composited daily or weekly. A deep-well-turbine pump in the recharge well was used to repump the water that was injected in each test, and samples of this recovered water were analyzed also.

Total iron, Fe^{+2}, HCO_3^-, dissolved oxygen, temperature, specific conductance, pH, and Eh were determined in the field by procedures outlined in Brown and others (1970). Additional parameters were determined at the Geological Survey laboratory in Albany, New York.

A comparison of chemical and physical data of the native water from the Magothy aquifer with those of reclaimed water is given in Table 1. Water from the Magothy aquifer at Bay Park is low in dissolved solids and is slightly acidic. Clay minerals, principally kaolinite, control the concentration of the alkali and alkaline earth elements through cation exchange (Pearson and Friedman, 1971). The concentration of silica approaches that in equilibrium with quartz, and the concentration of Fe^{+2} and SO_4^{-2} are controlled by pyrite (Vecchioli and others, 1974; Faust and Vecchioli, 1974). The pH of the water is controlled by both the dissociation of H_2CO_3 and the silica-kaolinite equilibria (Faust and Vecchioli, 1974, p. 372). The water is devoid of dissolved oxygen and has a negative Eh.

The reclaimed water contains much higher concentrations of most constituents than the native water from the Magothy aquifer (Table 1). Of significance here are NH_4^+, dissolved oxygen, and COD concentrations, which are absent or are at low concentrations in the native water.

CHANGES IN IRON CONCENTRATION AND pH DURING RECHARGE

Although the concentration of total iron in both native and reclaimed water was less than 0.5

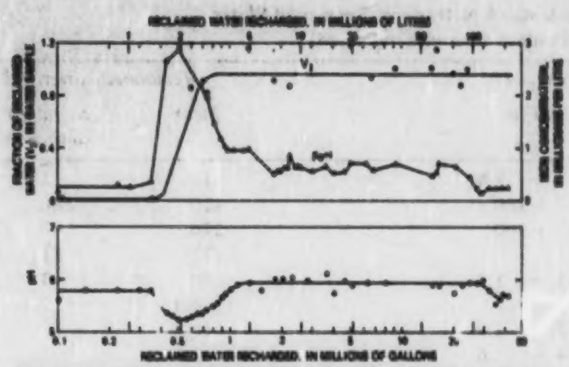

Fig. 3. Change in iron concentration, pH, and the fraction of reclaimed water (V_I) calculated for chloride at the 20-ft (6.1-m) observation well.

mg/l (Table 1), iron concentration in mixed water taken during recharge from the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) observation wells approached 3 mg/l as reclaimed water displaced native water. This concentration is an order of magnitude greater than the U.S. Public Health Service standard for drinking water (1962). Moreover, the concentration of total iron in water passing the observation wells increased with distance from the recharge well. This suggests that processes causing iron mobilization are not confined to the immediate vicinity of the recharge well and that they may continue to degrade water quality with distance from the recharge site.

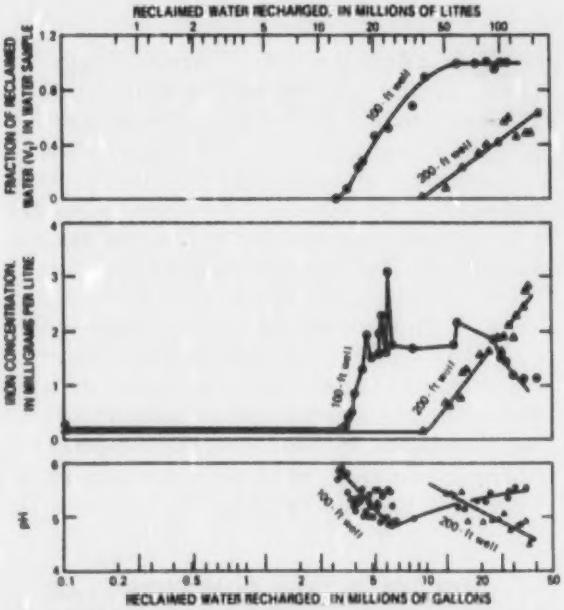

Fig. 4. Change in iron concentration, pH and the fraction of reclaimed water (V_I) calculated for chloride at the 100-ft (30-m) and 200-ft (61-m) observation well.

As reclaimed water displaced native water from the vicinity of the observation wells, pH decreased. Minimum values reached were successively lower with distance from the recharge well.

The change in iron concentration and pH in water passing the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) observation wells is shown in Figures 3 and 4. To determine the extent of mixing between native and reclaimed water during recharge, a dilution value, V_I, was calculated (F. J. Pearson and G. D. Bennett, written commun., 1971). This value is defined as:

$$V_I = \frac{C_s - C_n}{C_I - C_n} \tag{1}$$

where V_I is the fraction of reclaimed water in the water sample, and C_s, C_n, and C_I are the concentrations of constituents in the water sample, native water and reclaimed water, respectively. Chloride ion was used to calculate V_I, as it does not react with the mineralogical constituents during movement through the aquifer. The value of C_s is based on analysis of the Cl^- in the particular water sample of interest. C_n is based on the average Cl^- concentration in native water. The concentration of Cl^- in the reclaimed water varied during recharge. The value used in the computation was a running average of the water calculated to be at the well at the time the sample was collected.

A simplified mixing model was assumed in calculating V_I (Ragone and others, 1975). With the model, recharged water is assumed to move radially from the recharge well as an expanding cylinder having a height equal to that of the depth interval of the recharge-well screen (418 to 480 ft or 127 to 146 m).

Using the V_I curve to indicate the amount of mixing of native and reclaimed water, one can see that Fe^{+2} increases and pH decreases simultaneously with the arrival of reclaimed water at the observation wells. At the 20- and 100-ft (6.1- and 30-m) wells, Fe^{+2} reaches maximum values of nearly 3 mg/l at V_I values of 0.4 and 0.5, then decreases as V_I approaches 1. This suggests that iron concentration increases in the reclaimed-water front as the reclaimed water displaces native water from the vicinity of the observation wells.

Native water in the vicinity of the 200-ft (61-m) well was not completely displaced by reclaimed water because of the inadequate length of the test. Whether the 3 mg/l Fe^{+2} concentration observed is the maximum concentration to be reached there or the Fe^{+2} concentration would decrease with continued recharge as it did at the 20- and 100-ft (6.1- and 30-m) wells is not known.

The pH of samples taken from the 20- and 100-ft (6.1- and 30-m) wells decreased with the first arrival of reclaimed water, reached a minimum at about the same point Fe^{+2} concentration reached maximum values, and then increased (Figures 3 and 4). At the 200-ft (61-m) well (Figure 4), the pH continued to decrease until the end of the test. The minimum pH value was successively lower at the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) wells, respectively.

INTERPRETATION OF DATA

Iron mass-balance calculations using data from an earlier test showed that the increased iron concentration in water passing the 20-ft (6.1-m) well could not be accounted for by iron in the reclaimed water (Ragone and others, 1973). This fact and the fact that the amount of iron in the water passing the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) wells increased with distance from the recharge site (Table 2) indicate that the source of the iron that was dissolved is in the aquifer. Because pyrite is the only known iron mineral in the recharge zone, the increase in iron around the 20-ft (6.1-m) well was probably caused by oxidation of pyrite by the dissolved oxygen in the reclaimed water (Ragone and others, 1973). This model fits the observations at the 20-ft (6.1-m) well. Dissolved oxygen concentration of the first 2 million gals of reclaimed water recharged was 5 mg/l. On the basis of this value, the concentration of Fe^{+2} produced by the oxidation reaction (equation 2)

$$FeS_2 + \frac{7}{2}O_2 + H_2O = Fe^{+2} + 2SO_4^{-2} + 2H^+ \qquad (2)$$

is calculated to be 2.49 mg/l. The calculated value is in good agreement with the observed value of 2.88 mg/l. However, water reaching the 20-ft (6.1-m) well had no detectable dissolved oxygen cencentration. Consequently, oxidation of pyrite by dissolved oxygen in the reclaimed water cannot account for the continued pickup of iron at the 100- and 200-ft (30- and 61-m) wells (Table 2). Other unresolved factors, perhaps including organic complexing, and auto-oxidation, may contribute to the continued mobilization of iron.

Not all the observed decrease in pH during the displacement of native water by reclaimed water can be accounted for by pyrite oxidation (equation 2).

Table 2. Iron Content[1], in Milligrams, of Water at the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) Observation Wells During Recharge

20-ft Well	*100-ft Well*	*200-ft Well*
6.4×10^7 mg	20.1×10^7 mg	18.5×10^7 mg[2]

[1] Values represent the areas under those parts of the iron-concentration curves that exceed native-water concentrations.

[2] This is a minimum value, as reclaimed water did not completely displace native water from the vicinity of the 200-ft (61-m) well.

The relatively high concentration of alkali and alkaline earth metals, and NH_4^+ in the reclaimed water, as compared with the concentrations of the same parameters in native water (Table 1), and clay minerals in the recharge zone caused cation exchange that released additional H^+ to solution.

To determine the extent and the direction of exchange reactions, V_I values for Na^+, K^+, Ca^{+2}, Mg^{+2}, NH_4^+ and HCO_3^- were plotted against the volume of reclaimed water recharged in Figures 5, 6 and 7. Because of the reactivity of several of the constituents under consideration, the V_I values for these will differ from the V_I values for Cl^-. V_I values greater than those for Cl^- at a given volume recharged indicate that the particular constituent

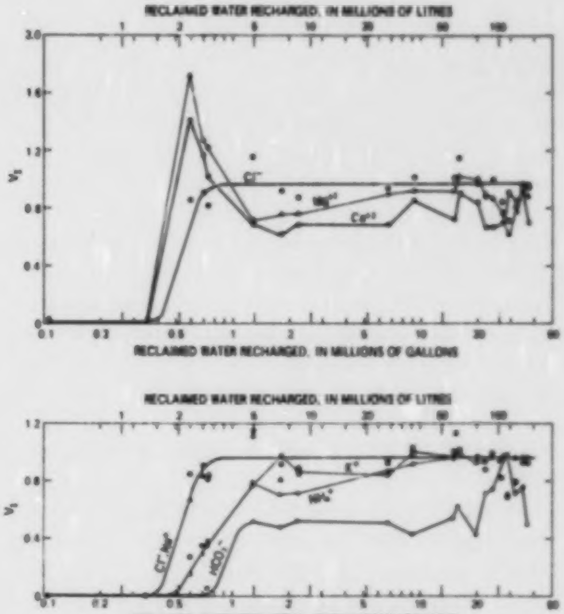

Fig. 5. Change in the V_I values for the major cations, chloride, and bicarbonate at the 20-ft (6.1-m) well.

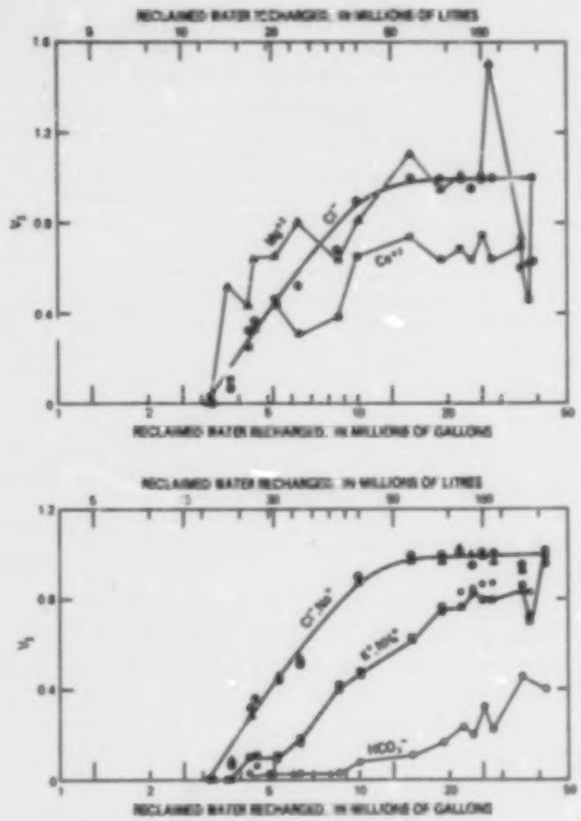

Fig. 6. Change in the V_j values for the major cations, chloride, and bicarbonate at the 100-ft (30-m) well.

concentration is greater than can be accounted for in a simple mixing model; values less than those for Cl^- indicate that the constituent concentration is less than can be accounted for by the mixing model. The HCO_3^- ion was included because it reflects the changes in H^+ described later.

Directing attention to the reclaimed-water front where pH values are minimum (Figures 3 and 4), one can see that, compared with Cl^-, concentrations of NH_4^+ and K^+ were less than can be accounted for using the mixing model (Figures 5 to 7). Na^+ behaves the same as Cl^-, and Ca^{+2} and Mg^{+2} show excess concentrations. The HCO_3^- curve reflects changes in H^+ concentration (Faust and Vecchioli, 1974) and indicates a loss as HCO_3^- or gain as H^+.

Examination of differences between calculated and observed concentrations of the exchangeable constituents in water from the 20-ft (6.1-m) observation well shows that, at 0.60 × 10^6 gal (2.3 × 10^6 l), when pH is near its minimum value, 1.32 meq/l more cations have been added to solution than removed (Table 3). This value is too large to result from experimental or sampling error and suggests reactions other than cation exchange also may be occurring. As Ca^{+2} and Mg^{+2} are the only cations that increase in concentration relative to Cl^-, these constituents are probably taken into solution by processes other than cation exchange. Deleting these cations and Na^+, which shows no significant change as compared to total concentration, from the cation balance results in very good agreement between the other added and subtracted constituents; NH_4^+ and K^+ account for a 0.94 meq/l loss from solution and H^+ accounts for 0.91 meq/l gain to solution.

Similar balances between NH_4^+ and K^+ lost and H^+ gained are seen at 0.70 × 10^6 gal (2.6 × 10^6 l) and 0.74 × 10^6 gal (2.8 × 10^6 l) (Table 3) where pH values remain low (Figure 3). Beyond this volume, pH has increased to that of reclaimed water and shows that native water has been displaced from the well site. Coincidentally, the milliequivalents per litre H^+ gained are no longer balanced by the NH_4^+ and K^+ lost.

The authors assume that concentrations of Ca^{+2} and Mg^{+2} observed as reclaimed water displaces native water from the vicinity of the 20-ft (6.1-m) well cannot be explained by cation exchange, but

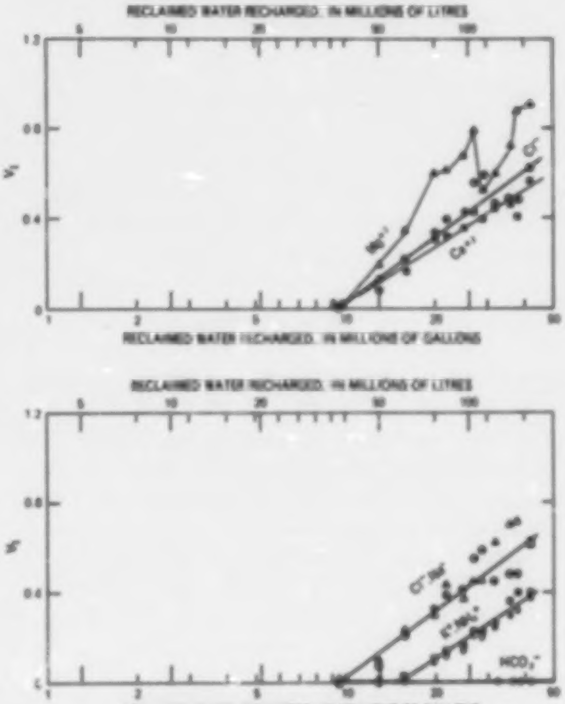

Fig. 7. Change in the V_j values for the major cations, chloride, and bicarbonate at the 200-ft (61-m) well.

Table 3. Differences Between Observed and Calculated Concentrations of the Major Cations and NH_4^+ and HCO_3^- in Water from the 20 ft (6.1 m) Well

Constituents	*Volume of Water Recharged* *0.60×10^6 gal (2.3×10^6 l)*	*0.70×10^6 gal (2.6×10^6 l)*	*0.74×10^6 gal (2.8×10^6 l)*	*1.3×10^6 gal (4.9×10^6 l)*	*2.2×10^6 gal (8.3×10^6 l)*	*9.1×10^6 gal (34×10^6 l)*	*22×10^6 gal (83×10^6 l)*
	Concentrations Observed Minus Concentrations Calculated in Milliequivalents per Litre						
Ca^{+2}	+0.66	+0.24	+0.12	−0.20	−0.21	−0.10	−0.25
Mg^{+2}	+ .58	+ .20	+ .16	− .15	− .03	− .02	− .03
Na^+	+ .11	− .19	− .30	+ .42	− .22	+ .11	− .05
K^+	− .11	− .16	− .17	− .05	− .03	+ .03	+ .02
NH_4^+	− .83	−1.00	− .95	− .29	− .42	− .07	0
$HCO_3^-(H^+)$	(+ .91)	(+1.15)	(+1.12)	(+ .57)	(+ .58)	(+ .34)	(+ .16)
Gain or loss[1]	+1.32	+ .24	− .02	+ .30	− .33	+ .29	− .15

[1] Plus sign indicates that cations have been added to solution; minus sign indicates that cations have been removed.

that changes in NH_4^+ and K^+ for H^+ result from cation-exchange reactions.

Similar but smaller exchange balances of NH_4^+ and K^+ for H^+ were calculated from data for the other observation wells during the periods when pH was at a minimum.

SUMMARY

Recharging the Magothy aquifer with tertiary-treated sewage resulted in a degradation in water quality with respect to iron concentration and pH. Iron concentration increased from the range 0.14 to 0.30 mg/l for native water to 3.00 mg/l at the 20-, 100-, and 200-ft (6.1-, 30-, and 61-m) observation wells, as the reclaimed water displaced native water. The increase was presumably a result of pyrite dissolution. The pH of the water decreased from the range 5.22 to 5.72 for native water to a low of 4.50, predominantly as a result of cation-exchange reactions.

ACKNOWLEDGMENTS

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DISCUSSION

The following questions were answered by Stephen E. Ragone after delivering his talk entitled "Chemical Interaction During Deep Well Recharge, Bay Park, New York."

Q. by Don Langmuir. *How did you determine your Fe^{3+} values—by filtration through 0.45 μ? Might the iron increases have been in colloidal suspension?*
A. Samples were filtered through 0.45 μ filters and analyzed for Fe^{+3} and total iron using the bipyridine method. It was found that iron in the native water and water collected at the observation wells during recharge was in the Fe^{+2} form. Fe^{+3} in the reclaimed water, presumably in the colloidal form was retained at the well-screen/aquifer interface (Ragone and others, 1973). As filters smaller than 0.45 μ were not used to filter the water from the observation wells, the presence of iron polymers or colloids smaller than this size may have been present but not detected.

Q. by Lyle V. A. Sendlein. *Did you make any mineralogical analysis of the aquifer materials?*
A. Some x-ray analyses of clays and microscopic analyses of sands were performed and are reported in greater detail in Vecchioli and others, 1974 (see References). Both the crystalline and amorphous phases in the aquifer are important considerations in understanding the chemistry of the system.

Q. by Donald Whittemore. *What is the time involved during the passage of the mixing front past a given point in the aquifer?*
A. Native water was displaced from the vicinity of the 20-ft well within several tens of hours after the start of mixing, and from the vicinity of the 100-ft well within about 20 days. Native water wasn't completely displaced from the vicinity of the 200-ft well even after 84.5 days of recharge.

Q. by Martin J. Allen. *What was the bacteriological quality of the tertiary-treated water prior to injection?*
A. Reclaimed water was chlorinated to a 2.0-2.5 mg/l total residual at the point of injection. Total bacteria counts were generally less than 10 per 100 ml and total coliform counts were generally less than 1 per 100 ml.

Q. by K. Bradley, Jr. *What form of tertiary treatment is used—sand filter or carbon?*
A. The tertiary-treatment process involves (1) aluminum sulfate treatment to precipitate phosphate and suspended solids; (2) dual-media filtration; (3) activated carbon filtration; and (4) chlorination.

Q. by M. K. Botz. *What relationships did you find for manganese?*
A. Manganese concentration in native water ranged from 10 to 50 μg/l and averaged 75 ±31 μg/l in the reclaimed water during the 84.5-day test. No significant changes in the concentration of this constituent were observed during the recharge experiment.

Editor's Note: *John J. Hickey's paper, "Deep Well Injection and the Protection of Fresh Ground-Water Resources, West Central Florida," does not appear here because it has not as yet been approved for publication by the U.S. Geological Survey.*

Development of Fresh Ground Water Near Salt Water in West Virginia[a]

by Benton M. Wilmoth[b]

ABSTRACT

Salt-water migration into relatively shallow rocks in the western half of West Virginia is already rather far advanced. Because of the wide distribution of salty ground water and connate brine at various depths, it is difficult to determine how much of the contamination is natural and how much is the result of subsurface industrial activities. Although some local salt-water problems are the result of oil and gas operations, much of the regional near-surface salt water is a natural condition unrelated to deep drilling or other industrial activities.

Ground water is usually more abundant from consolidated aquifers beneath the valleys than from beneath the ridges. However, the presence of shallow salt water beneath the valleys imposes limitations on the availability of fresh water from a single well. Because most well fields must be located along the populated valleys, the problem of interception of salt water is the most important factor limiting development of consolidated bedrock aquifers. By utilizing the history of development and operation of well fields, an estimate of the availability of fresh water can be made, and test drilling and new well field construction guided accordingly.

During 1971 to 1974, more than a dozen small communities in Logan and Boone Counties started development of public-water supplies from wells. Existing water-supply problems in these areas are being solved by using the cumulative experience of other communities in the area. Ground water is currently being developed in valley areas of Logan County such as Man to Lorado, Essie to Big Creek, and Huff Creek to Mallory. Adequate well fields have recently been successfully constructed just above shallow salt water in bedrock aquifers at Hattie in Calhoun County, near Madison in Boone County, near Southside in Mason County, and at Prichard in Wayne County. In all of these areas of successful construction, the essential information for initial test drilling was obtained by detailed hydrogeologic work at the prospective sites. Most important was the determination of the maximum depth of fresh water, well spacing and pumping rates.

During the next few years, new small communities and industries in West Virginia will need to develop water supplies and some existing communities will have to consider additional sources of supply because of increase in water use. Such water-supply problems can be solved by using the experience of others in ground-water development and the history of operation of both existing and abandoned well fields.

Ground water has historically been regarded as a quantitatively minor water source with the principal users being rural residents. In fact, however, this resource represents more than 90 percent of the available fresh water in the State. Ground-water systems are used by more than 300 communities and most rural residents, which totals 55 percent of the State's population. In addition, some 400 industries and 8,000 businesses, institutions, and dairy farms also utilize well systems for all requirements. Although ground water is known by geologists to be an imperative in water resources development, this major resource is, at times, not considered by developers (Lehr, 1972). Reasons for this appear to be that ground water cannot be seen or estimated during initial planning and reconnaissance, and that subsurface hydrologic conditions present a strange and bothersome unknown. This unfortunate lack of knowledge on the part of water developers and planners is being corrected as rapidly as possible by those involved in ground-water conservation programs.

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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One important aspect of the water conservation effort is to determine the amounts of water that can be obtained from the available local aquifers on a sustained basis.

The most productive consolidated aquifers are sandstone, conglomerate, and limestone. Although shales are not as productive, the near-surface fracturing usually allows development of well fields of small to moderate yields.

The yield of wells depends upon the local hydrogeology. Most important is the permeability of the aquifers, but topography and the shape of the water table also have an effect. Relatively shallow wells drilled in valleys tend to produce more water than deeper wells drilled higher on ridges, because in valleys the zone of fracture enlargement and weathering is more likely to be saturated by ground water. Shallow rocks on ridges are as permeable, but usually occur above the zone of saturation and therefore do not contribute to well yield.

The depth of existing water wells ranges from less than 25 to about 300 feet; however, the average depth is only about 115 feet. Many public supplies have been pumped daily for more than 45 years with no record of water shortage during drought periods. This indicates that the practical sustained yields of these systems have never been exceeded. Records of ground-water storage show that over long periods the recharge to aquifers equals the amount of discharge. Only in heavily pumped or overdeveloped local aquifer areas or during periods of extreme drought has discharge exceeded recharge to affect storage temporarily (Wilmoth, 1965).

The quantity of ground water discharged naturally from both consolidated and unconsolidated aquifers greatly exceeds the quantity of water that is withdrawn by wells. In many areas, the potential for development of ground-water supplies exceeds the projected industrial and community development.

Consolidated bedrock aquifers underlie most of the land surface of the State and are the principal source of water for more than 250 communities, many industries, and rural businesses, schools, and farms. A particularly favorable area for ground water is a large section of predominantly sandstone aquifers of lower Pennsylvanian age that extend 200 miles through the central part of the State (Figure 1). The area is about 25 miles wide in the north and 50 to 75 miles wide in the south. These water-bearing rocks from oldest to youngest include the Pottsville Group, the Allegheny Group, and the lower part of the Conemaugh Group. Yields of industrial and public supply wells range from less than 50 to 1,000 gallons per minute (gpm) and average about 200 gpm. Supplies of 0.5 to 1 million gallons per day (mgd) have been developed locally from these aquifers with 3 to 5 wells (Wilmoth, 1967). Salty ground water has invaded parts of these aquifers along the western edge of the area of outcrop.

In the typical shale and interbedded sandstone areas, the uppermost or shallowest weathered or fractured beds are the most favorable aquifers. Few wells yield large supplies from deeper predominantly shale zones. Ground-water availability of shale areas, although not high, is still adequate for private rural business and farm supplies. Most shale sections have some siliceous zones or fine-grained sandstone beds. The extent of development of near-surface fractures appears to be most important in the storage, transmission, and availability of water. Yields of industrial and public supply wells range from less than 20 to more than 150 gpm with an average of about 30 gpm. Supplies of 0.1 to 0.5 mgd have been developed with 3 to 5 wells tapping zones of relatively high permeability. The aquifers of the upper Conemaugh Group and the Monongahela Group of Pennsylvanian age and the Dunkard Group of Permian (?) age crop out in the western part of the State (Figure 1). Relatively shallow salt water occurs beneath the major stream channels. In eastern West Virginia, the shallow shale and sandstone aquifers of pre-Pennsylvanian age have not been invaded extensively by salt water.

Water-bearing carbonate rocks of pre-Pennsylvania age of the eastern part of the State have good local productive aquifers (Figure 1). However, the water-saturated cavernous zones are very erratic requiring study and test drilling to develop moderately large supplies. Yields of

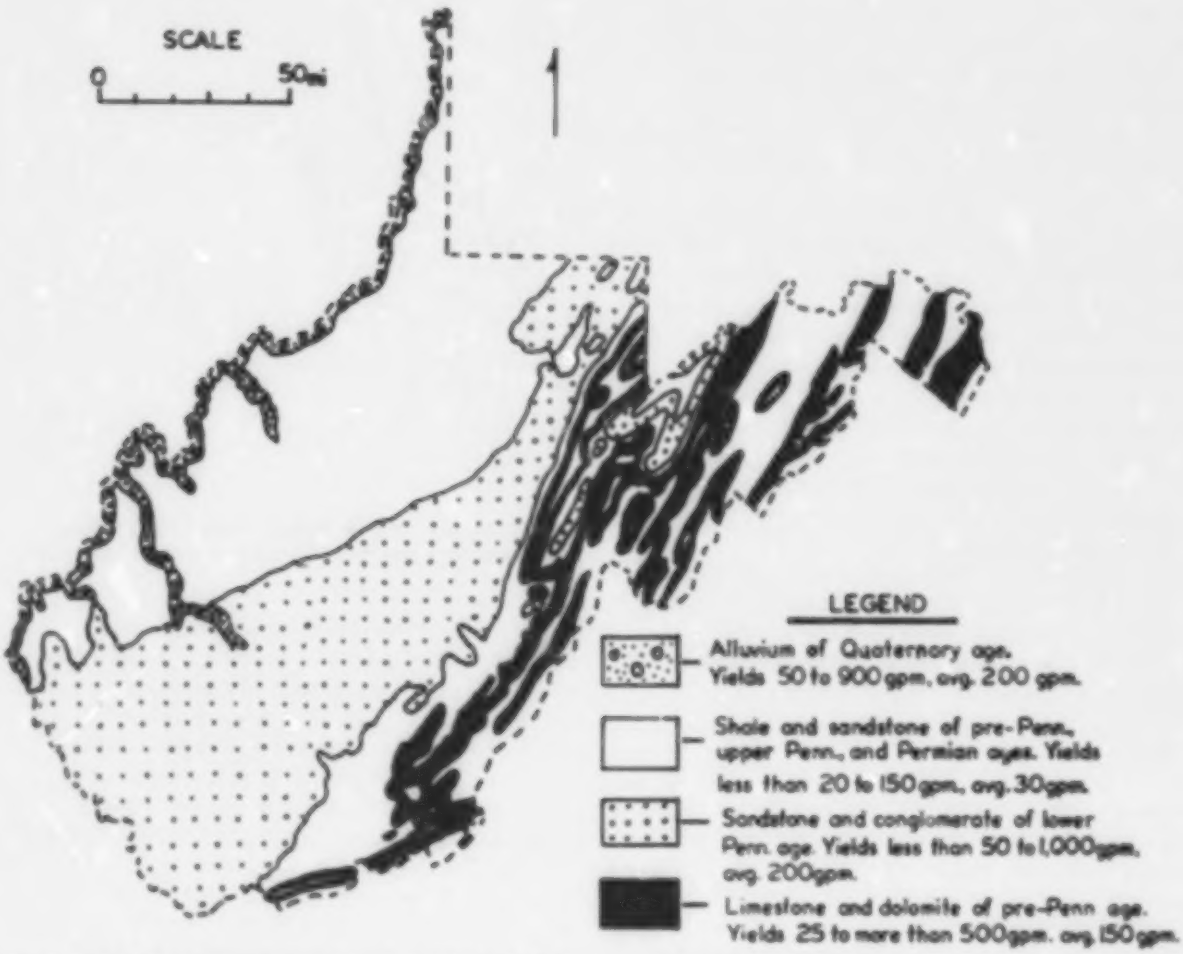
SCALE
0
50mi
LEGEND
Alluvium of Quaternary age. Yields 50 to 900 gpm., avg. 200 gpm.
Shale and sandstone of pre-Penn., upper Penn., and Permian ages. Yields less than 20 to 150 gpm., avg. 30 gpm.
Sandstone and conglomerate of lower Penn. age. Yields less than 50 to 1,000 gpm., avg. 200 gpm.
Limestone and dolomite of pre-Penn age. Yields 25 to more than 500 gpm., avg. 150 gpm.

Fig. 1. Availability of ground water from industrial and public water-supply wells in West Virginia.

industrial and public supply wells range from less than 25 to more than 500 gpm with an average of about 150 gpm. Supplies of 1 mgd have been developed in areas where 3 to 5 wells penetrate interconnected water-bearing cavernous zones. These shallow aquifers have not been invaded by natural salty ground water. Locally, however, unnatural contamination has occurred from salt used on highways and from salt piles exposed to weather.

A highly productive water-bearing rock unit is the unconsolidated glacial outwash sand and gravel alluvium of Pleistocene age (Carlston and Graeff, 1955). These aquifers border the Ohio River Valley, the lower half of the Kanawha River Valley, and a few miles upstream from the mouth of Big Sandy River, Guyandotte River, Coal River, and Little Kanawha River (Figure 1). The alluvium varies in width from a few hundred feet to several miles and in thickness from 40 to 150 feet. Many large industrial plants and about 50 communities use well fields tapping these rocks.

Although unconsolidated sand and gravel aquifers constitute some of the best aquifers in the State, they underlie only about one percent of the total land area. At established well fields, yields of wells range from less than 50 to more than 900 gpm and average about 200 gpm to standard vertical screened wells. Well fields of 3 to 5 wells commonly produce 0.5 to as much as 3 mgd of good quality water. Yields of large-diameter radial collectors range from 1,000 to 3,000 gpm or more and single installations produce 1 mgd to as much as 4 mgd where induced infiltration of the Ohio River is part of the system.

The alluvial aquifers along the Ohio River also contain salt water in places. Small segments of ancient stream channels cut in the bedrock of the present valley are now filled with alluvium. Along the valley in Hancock, Brooke, Tyler, and Cabell Counties certain of these filled depressions have been intercepted by salt water that has migrated from the adjacent bedrock. High-capacity wells installed nearby have induced the migration of the salt water.

Sedimentary rocks of Pennsylvanian and Permian (?) ages of the western half of the State form a complex, alternating series of sandstone, shale, conglomerate, siltstone, limestone, and coal strata. The rocks are gently folded along subparallel axes that trend generally northeastward. These flexures tend to obscure the general regional dip of the strata toward the northwest. Because of their structural folding and the subsequent erosion over geologic time, some of the older brine-bearing rocks are now relatively near the land surface along the axes of some major anticlines.

The developed fresh ground water usually has a chloride concentration in the range of 10 to 100 mg/l, although in places, ground water containing 250 to as much as 500 mg/l is utilized by necessity. However, salty ground water is defined as that containing more than 250 mg/l chloride concentration.

Table 1 shows concentrations of chloride in ground water as related to depth of wells located along major valley areas. The Table presents data to show that chloride concentration in the ground water tends to increase with depth as the effects of fresh meteoric ground water decreases. At depths of 1,000 to 5,000 feet, connate brines are usually encountered that contain 30,000 to 100,000 mg/l of total dissolved solids (Price, *et al.*, 1937, pp. 28-32). These brines were derived from sea water trapped in the original rock-forming sediments. At depths of 1,000 to 5,000 feet, the natural migration apparently is extremely slow. The various processes of chemical concentration and modification of the original sea water are not completely understood.

In areas where there has been no deep drilling, the natural vertical migration of brine and salty ground water appears to be extremely slow. Natural changes in the quality of both fresh and salty ground water in these rocks appear to be minor over several hundred years. The few historical data available for specific aquifers indicate no large-scale natural variations in chloride content (Wilmoth, 1970). Most of the salt-water migration into the near-surface rocks occurred naturally from a long period of interformational migration of artesian brine. The migration apparently has occurred during several million years of geologic time.

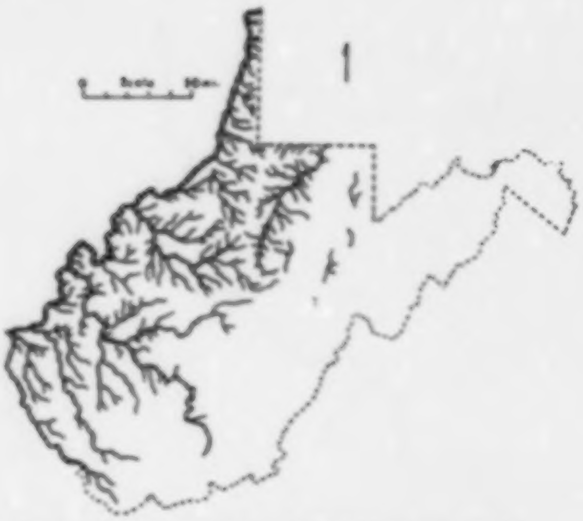
Fig. 2. Valley areas in West Virginia where fresh ground water is limited to less than 300 feet below stream channels.

Relatively shallow rocks throughout the western half of the State have been invaded in the geologic past by connate brine (Figure 2). The magnitude of this encroachment has been realized principally from the development and operation of industrial and public water-supply wells. Examples of fresh ground-water development near salty ground water include both natural occurrences of salt water and unnatural encroachment of salt water caused by stresses placed on the subsurface environment by man. Salt-water encroachment into existing fresh-water aquifers is usually the result of some industrial activity. Both vertical and lateral encroachment can be caused by (1) reduction of fresh-water head due to heavy pumping, (2) drilling

Table 1. Concentrations of Chloride in Ground Water as Related to Depth of Wells Located in Major Valleys

Number of samples of well water analysed	*Range in depth of wells (feet)*	*Percentage of samples exceeding 250 mg/l chloride in each range*	*Average concentration of chloride higher than 250 mg/l*
319	20 to 99	5	700
238	100 to 149	13	900
116	150 to 299	26	1,300
43	300 to 600	65	8,300

too deep and intercepting salt-water zones, and (3) imposing greater head on salt-water zones from injection of waste brine, repressuring of oil-producing zones, and hydraulic fracturing of rock units at oil and gas operations (Wilmoth, 1970).

Local areas of these shallow fresh-water aquifers have been contaminated by vertical migration of salt water through unplugged test holes and improperly abandoned wells. In areas of oil, gas, water, and coal development over the past 75 years, many hundreds of such test bores and wells were put down and still exist as essentially open holes. These holes represent a large increase in local vertical permeability that allowed rapid migration upward of brine under artesian pressure.

Because salty ground water also occurs naturally at relatively shallow depths, it has been difficult to determine unnatural conditions except for the characteristic of extreme variation in chloride content within short periods. The available historical data for specific aquifer areas indicate no large-scale natural variations in salt content. Prior to pressure disposal of produced waste brine, the natural salty ground water occurring immediately below fresh-water aquifers posed no problem to shallow water well fields pumped at low rates.

During the period 1971 to 1974, several small communities in Logan and Boone Counties started development of new water systems from ground-water sources. A considered major factor was that the cost of treated ground water at the household tap is usually only 10 to 30 percent of the cost of treated surface water at the tap.

Salty ground water is commonly encountered at depths of less than 300 feet beneath the Ohio, Kanawha, Big Sandy, Coal, and Little Kanawha Rivers (Figure 2). The natural fresh ground-water head in these areas has not been great enough to keep salty ground water from migrating into shallow rocks beneath the valleys. In areas of extensive well field development where large amounts of fresh water are extracted, a reduction in the head of fresh-water aquifers can cause upward migration of the salt-water interface. As a result, the salt water tends to migrate into the fresh water zones of lower head.

In the Charleston area of Kanawha County, along the Kanawha River Valley and the mouth of the Elk River, withdrawal of large amounts of fresh water from the principal aquifer was a significant factor in accelerated encroachment of salt water. In 1930, the salt-water interface was about 400 feet above mean sea level, but by 1950, the interface had moved upward 75 to 100 feet beneath major pumping centers. Chloride content of ground water in the principal sandstone aquifer increased from less than 100 mg/l to more than 300 mg/l in several well fields and to more than 1,000 mg/l at individual wells (Wilmoth, 1972).

Similar encroachment also occurred at well fields in South Charleston and in the Kanawha City area of Charleston.

At Ashford, Boone County, along Big Coal River, the salt-water interface lies at about 570 to 580 feet above mean sea level. High-capacity wells initially penetrated the interface 50 feet or more, depending on the topographic location of the wells. Each well in the field is pumped periodically at a rate of 250 gallons per minute (gpm). Records of chloride content during 1971 show that chloride increased from 880 mg/l to 933 mg/l at one well and from 630 mg/l to 938 mg/l at another well. In order to reduce this salt-water encroachment, consideration has been given to experimentally decreasing the pumping rates perhaps to as low as 25 gpm. In order to have the same amount of water available, pumping time will be longer, storage facilities will be enlarged, and finally more wells that do not interpret the salt-water interface have to be considered for the well field.

Three miles west of Southside, Mason County in an upland area, the salt-water interface is at an elevation of about 500 feet. Wells drilled through the hill from elevation 720 feet, 262-feet deep encountered salt water. New wells drilled 160-feet deep produce adequate supplies of fresh water.

At Prichard, Wayne County, in the Big Sandy River Valley a well field was constructed to serve as a semi-public supply. In this area the salt water occurs about 175 to 200 feet below the land surface. Three wells of extremely low yield have been successful in producing a sufficient amount of fresh water. This has been accomplished by using longer pumping periods and larger storage tanks. The maximum depth of these wells is 130 feet.

A successful well field for semi-public water supply was constructed at Hattie, Calhoun County, early in 1974. The land surface is at an altitude of 710 feet and the estimated altitude of the salt-water interface was 575 to 600 feet. Adequate wells of 30 gpm each were drilled to a depth of 130 feet.

In 1974 near Madison, Boone County, another semi-public supply well field was successively constructed near salt water. The site is at an elevation of 750 feet and the top of the salt-water zones were estimated to be at 550 to 590. Two wells, 150-feet deep were drilled and produce 40 and 20 gpm of fresh ground water.

In the Man to Kistler area of Logan County, the salt-water interface lies at about 600 to 625 feet above mean sea level. Therefore, wells drilled along Guyandotte River can be no deeper than about 150 feet to avoid intercepting salt water. Along Buffalo Creek tributary to the Guyandotte in the Accoville to Amherstdale area, wells can be drilled as deep as 200 feet. In the Lorado area, wells as deep as 500 feet have not encountered salt water. This tends to substantiate the general concept that the stream channels act as areas for the natural discharge of all ground water and that the salt-water interface tends to cone up more toward the lowest drainage levels. Construction of wells in this area has proceeded with no problems of salt-water contamination.

In the Huff Junction to Mallory area of Logan County, the salt-water interface lies at about 125 to 150 feet below the channel of Huff Creek; consequently wells located near Rt. 10 along the valley cannot be drilled much deeper than about 100 feet. Along nearby Riddle Branch, the land surface rises considerably within a short distance. Here, wells can be drilled as deep as 200 to 250 feet and still produce fresh water. Similar elevation of land surface, depths of wells, and quality of ground-water relationships exit along other topographically higher tributaries to Huff Creek.

In the Essie to Big Creek area of Logan County, along the Guyandotte River, the salt-water interface is extremely shallow and lies at about 550 feet above mean sea level. Consequently, most fresh-water-producing wells must be no deeper than about 80 feet if they are located near Route 10 that follows the valley. In order to test a greater thickness of fresh-water aquifer, wells should be located at higher elevations on valley slopes and nearby small tributary valleys that lie topographically higher. Recent extensive test drilling in this area has confirmed the general aspects of the topographic and hydrogeologic controls on natural shallow salty ground water.

Possibly the most difficult problem in ground-water quality control is to predict within narrow limits the movement of a pollutant in an aquifer when concentrations of the pollutant are decreased by dilution. The problem is even more complex when the pollutant is natural salt water, which occurs in adjacent rocks at a wide range of concentrations, depths, and velocities. Therefore, it is difficult to ascertain when salt water has occurred naturally and what future subsurface conditions will be.

All of the hydrogeologic conditions that have made shallow fresh-water aquifers subject to contamination by salty ground water are not known. The best available information has been from records at well fields that were contaminated after some period of successful operation. While the subsurface conditions cannot be described with extreme accuracy, it is possible to define the general occurrence of the salt water.

It is important to note that most of the unnatural salt-water contamination of fresh-water aquifers has been detected only because of the deterioration of the water quality pumped by wells. Had there been no water well developments in these areas, the aquifer contamination might never have been defined. Therefore, serious aquifer contamination can occur in numerous places and not be known until attempts are made to develop the ground water.

Within the past 8 years (1967-74) in the oil-producing areas of Kanawha and Roane Counties, pressure injection of waste brine into the Salt Sandstone of the Pottsville Group of Pennsylvanian age has raised the piezometric levels of natural fluids in the formation. Because the overlying fresh-water zones are hydraulically connected to the injection zone, there has been extensive salt-water pollution of the fresh-water aquifers. Unnatural cyclic changes in quality have occurred in many private water well supplies. Monitoring of the water quality in developed aquifers has revealed unnatural fluctuations in chloride content. Extreme changes have been detected within a few days. Chloride concentrations in some places increased from less than 100 mg/l to as much as 900 mg/l.

In the area of Walton in Roane County, produced waste brine was injected into sandstones of the Pottsville Group at a depth of about 1,500 feet. Many uncased and improperly plugged abandoned oil wells in the area provided additional permeability for vertical movement of the salty ground water. Apparently the artificial raising of the piezometric level of the natural brine triggered the salt-water contamination because the fresh-water aquifers are hydraulically connected to the salt-water zones. At certain water wells in the Walton area, contamination was rapid with chloride content increasing from less than 25 mg/l to more than 1,500 mg/l within a few months. During 1968 and 1969, unnatural cyclic changes in chloride content occurred at many wells. In one part of a shallow fresh-water aquifer, the chloride concentration of less than 50 mg/l increased to 1,150 mg/l in 19 months. After brine disposal operations were altered in 1970, the chloride content of water in this part of the aquifer declined to 68 mg/l within 17 months, but other wells in Walton remain highly contaminated by salt water.

Planning, design, and construction of an adequate well field in these relatively shallow consolidated aquifers require detailed hydrogeologic data with expert interpretation. Before the initial test drilling is started, expert advice on the local hydrogeology and quality of ground water should be obtained. This will help to assure successful development where shallow salt water is present. Large monetary losses and failure of test wells have been common where this guidance was not utilized. In addition, some initially successful well fields have decreased in value because of water quality deterioration from excessive pumping rates. Where well-field withdrawals are expertly managed, upward migration of the underlying salt water is not a problem. With adequate controls on subsurface activities, much of the unnatural salt-water contamination of fresh-water zones can be prevented.

The general extent of brine intrusion into shallow aquifers is known, and water-supply developers can plan construction of a well field in advance if they obtain the necessary hydrogeologic guidance. Before production wells are planned, it is important to know the depth of the shallowest salt water and the maximum depth of fresh water in each prospective test site. Ideally the property should not be purchased until an adequate water supply is assured, but unfortunately, this procedure is rare.

Although high iron, manganese, sulfate, and total dissolved solids present problems in treatment, they are generally solved at an acceptable cost. High chloride content, however, tends to limit development of the consolidated aquifers, because of the high treatment costs involved and the extreme corrosiveness of the salt on pumping and transmission equipment. The best approach is to avoid production of salty water if at all possible.

Where the salt water lies less than 100 feet below the base of the stream channel, test wells should be located on a higher terrace or slope. In some places, it may be necessary to locate test wells some practical distance along nearby tributary valleys. These tributary channels usually lie topographically higher, and consequently a greater thickness of fresh-water aquifer will usually be available.

Industrial and community expansion will increase ground-water use in most areas. Development of new well fields over larger areas and reduction of pumpage in existing well fields near salt-water zones will help to reduce encroachment of salt water and conserve fresh-water aquifers in critical areas. In order that overdevelopment may be detected before depletion or salt-water encroachment become critical, pumpage inventories and chemical analyses should be made periodically and correlated with records of ground-water storage. These procedures can provide enough data to indicate where contamination is occurring and offer a basis to begin remedial work.

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DISCUSSION

The following questions were answered by Benton M. Wilmoth after delivering his talk entitled "Development of Fresh Ground Water Near Salt Water in West Virginia."

Q. *Do you use a drawdown-depth to salt-water relationship to limit pumping rates?*
A. Yes. The pumping rates can be experimentally reduced to half and then half again if necessary. In general, with the relatively shallow wells, it is prudent to conserve half of the available drawdown.

Q. *Doesn't removal of oil and brine result in less fluid to return to the aquifer—the net result being less pressure to salt aquifers?*
A. Yes, and generally over the years there has been reduction in pressures from production of oil, brine, and natural gas.

Q. *What is the origin of the brine in deeper bedrock in West Virginia?*
A. Brine in deeper bedrock is the natural connate brine and can be associated with oil and gas production.

Q. *Does the saline water in the upper saline zone derive from the brine? If so, what is the nature of the hydraulic continuity?*
A. Saline ground water in the upper saline zone is a mixture of brine and fresh meteoric ground water. The hydraulic continuity can be natural fracture systems in conjunction with many abandoned open holes from oil and gas production that were improperly plugged.

Q. *How does the generalized occurrence of salt water relate to the geology?*
A. Relatively shallow salt water occurs throughout the western half of the State in rocks of Pennsylvanian age and of Permian (?) age. In general, the salt-water—fresh-water interface cuts across geologic contacts.

Q. *Have you developed a method of determining the injection brine from native mineralized water?*
A. No. The injection brine and the native mineralized water usually are associated with the same general rock sections, and therefore the chemistry can be rather similar.

Q. *The fresh-water—salt-water contacts in diagrams are mostly horizontal. What kind of control data do you have?*
A. The elevation of the fresh-water—salt-water interface at particular locations is based on data from water wells that actually penetrated the interface. In local well fields this may appear to be horizontal.

Subsurface Biological Activity in Relation to Ground-Water Pollution[a]

by James F. McNabb and William J. Dunlap[b]

ABSTRACT

Biological activity occurring in subsurface regions below the soil zone may be of considerable importance in determining the fate and effect of pollutants in ground water, but this possibility has received little previous attention. This paper comprises a discussion of subsurface biological activity in regard to ground-water pollution as reflected by available literature references. The subsurface environment is discussed in terms of factors likely to be of greatest significance in regard to the development of biological systems, and previous investigations of subsurface microbial activity are reviewed. Available information indicates the presence in the upper continental crust of the earth of numerous regions, particularly those of sedimentary origin, which are probably suitable habitats for many microbial species. Previous investigations of subsurface microbial activity clearly show the presence of diverse microbial populations in many subsurface regions below the soil zone. Hence, microbial activity appears both possible and probable in most subsurface regions of importance in regard to ground water. Further elucidation of the extent and nature of microbial activity in subsurface regions is needed in developing methods for predicting the impact on ground-water quality of pollutants released into the earth's crust.

INTRODUCTION

Pollutants are most likely to enter ground waters by either of two principal pathways: percolation through the unsaturated portion of the earth's crust above the water table or discharge directly into ground water without passage through the upper soil layers. Both during percolation through the crust of the earth above the water table and within saturated ground-water zones, pollutants are subject to possible sorption, abiotic chemical alteration, and chemical alteration resulting from biological activity. Of the three possibilities, biological alteration may well be of greatest potential importance in determining the ultimate effect of a pollutant on ground-water quality.

The topmost layers of the earth's crust, comprising that region considered by the soil scientist as true soil as opposed to subsoil and underlying substratum, have been rather thoroughly studied, principally because of their importance to agriculture, and have been shown to comprise a region of relatively intense biological activity. Hence, pollutants percolating through the soil zone are known to be subject to potential degradation as the result of the metabolic activities of a multitudinous population of biochemically diverse microorganisms within this region. However, those regions of the earth's crust lying below the soil zone have received much less attention in regard to their biological activity. Consequently, the possibility of biological alteration of pollutants in these regions, as well as possible effects of pollutants on subsurface ecosystems, has been given little serious consideration.

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Knowledge of the biological activity which occurs or can be expected to occur in the subsurface environment is important in determining the fate and effect of pollutants in ground water. This paper comprises a discussion of currently available information concerning subsurface biological activity and those environmental factors likely to be most significant in regard to development of biological systems. Principal attention has been devoted to those regions of the earth's crust lying below the soil zone, since numerous compilations of information concerning biological activity in the soil are widely available.

THE SUBSURFACE AS A BIOLOGICAL HABITAT

The subsurface environment is a highly structured environment which is not homogeneous but varies from point to point, encompassing a wide range of environmental conditions. Organisms inhabiting the subsurface will be essentially restricted to the "living space" provided by the voids, or interstices, of the rock comprising the upper portion of the crust of the earth. (The term rock is used here in the broad sense, meaning any solid constituent of the earth's crust). These interstices differ widely in size, shape, arrangement, and aggregate volume. They range in size from large solution cavities through all gradations to minute pores. They may be closely interconnected or relatively isolated.

Porosity data (Walton, 1970; Todd, 1959) indicate that the total interstitial space per unit volume of rocks comprising the upper crust of the earth, with the possible exception of massive crystalline rocks containing no joints or fractures, is adequate to permit at least some microbial activity, provided the sizes of the individual interstices are sufficient to accommodate the dimensions of the microorganisms. Although the sizes of interstices in most rocks have not been quantitatively determined, various studies involving the transport of bacteria through rather dense rocks suggest that bacteria might find adequate space to exist and function in wide regions of the subsurface (Kalish *et al.*, 1964; Myers and McCready, 1966). Certainly, spatial limitations would not appear likely to exclude as microbial habitats those subsurface regions of sufficient porosity and permeability to permit transmission and storage of appreciable quantities of water. These are, of course, the regions of greatest interest in regard to ground-water pollution control.

Spatial limitations are also of concern in the transport of microorganisms into and within subsurface regions by moving water. Obviously, physical difficulty in negotiating small interstices as well as possible sorption on solid substances are likely to greatly impede the movement of microbes through the interstitial space of subsurface formations. Investigations of the transport of bacteria through subsurface materials have primarily pertained to the movement of pathogens and indicator bacteria from sewage and not necessarily microorganisms likely to have a long life span in the subsurface environment (Mallmann and Mack, 1961; McGauhey and Krone, 1967). These studies suggest that the principal deterrents to movement of the bacteria studied often were factors other than physical impediment and suggest that bacteria which are capable of surviving in the subsurface environment might be able with time to travel great distances with percolating water.

Within the unique habitat provided by the interstices of the earth's crust, any native or introduced microorganisms will be subjected to various environmental extremes. The ability of these microorganisms to cope with subsurface conditions will determine not only whether the microorganisms merely survive, but will also determine whether an active biological community will develop capable of modifying its environment.

One potential problem will be high osmotic pressures. Because of the great solvent power of water, ground water usually reflects to some extent the chemical composition of the rock formations through which it moves. In general, the mineral content of ground waters increases with depth and may reach levels in excess of 20 percent total mineral content in deep formations, particularly those which appear to be hydrogeologically isolated (Kuznetsov *et al.*, 1963; White *et al.*, 1963). Ground waters of high mineral content are also found in relatively shallow rock formations which are partly composed of salt beds deposited from ancient seas. In those regions of the zone of saturation where ground waters are highly mineralized the availability of water to many microbes would, in effect, be severely restricted because of high osmotic pressures. However, bacteria differ greatly in their ability to withstand and adapt to high osmotic pressure, and many species have been found to grow in highly mineralized waters, including some which tolerate as much as 30 percent salt (Zajic, 1969).

Temperature is one of the most important environmental factors controlling the metabolic activity of microorganisms in any type of habitat, and considerable information has been developed concerning the relationship of temperature to the growth and survival of microorganisms. For mesophilic organisms, which comprise by far the greatest number of microbes, the optimum growth range is 25-40° C. Thermophilic organisms have an optimum growth temperature of 55-60° C, but some can continue to grow at temperatures as high as 75-90° C at atmospheric pressure. The maximum temperature that all but a few heat-resistant spore-forming bacteria can tolerate without being killed is normally considered to be 100° C, but most microorganisms are actually killed by temperature much above 50° C (Rose, 1968). The minimum temperature limits at which microorganisms grow may be as low as −15° C in waters with a high concentration of solutes (Vallentyne, 1963). Many psychrophilic bacteria are found in nature which can grow fairly rapidly between 0° and 5° C, although the optimum growth temperatures for many psychrophiles are often in the same range of 25-40° C (Rose, 1968; Brock, 1966).

The temperature tolerances of microorganisms may be affected by other environmental factors. For example, high acidity seems to lower the maximum temperature at which growth may occur (Brock and Darland, 1970). Pressure and temperature are definitely interrelated, the maximum temperature for growth being raised 5-20° C by compression according to ZoBell (1958).

Temperatures in the earth's crust rarely fluctuate, except in the topmost layer of approximately 10 m (33 ft) which may be affected by seasonal temperature variations (Kuznetsov *et al.*, 1963). The normal ground-water temperature at depths of 9-18 m (30-60 ft) roughly corresponds to the mean annual air temperature of the given region and ranges from about 3° C (37° F) to 25° C (77° F) in the United States (Geraghty, 1967). As the depth increases, the temperature of the subsurface rocks and waters increases; this increase is roughly estimated to be 30° C per 1,000 m (3,281 ft) (Sanders, 1967).

Based on upper temperature limits of 80° C and 100° C, respectively, for microbial growth and survival, and assuming a 30° C increase in temperature per 1,000 m of depth, it would appear that high temperatures would likely prevent most microbial activity in subsurface environments lying below approximately 1,800 m (5,900 ft) and virtually preclude the existence of microbes in those environments at depths below about 2,500 m (8,200 ft). These values are, however, only very rough guidelines subject to wide variation, since temperature within the earth's crust at any particular geographical location are likely to reflect not only depth but also geologic structure and geothermal activity. Hence, high temperatures may sometimes occur at relatively shallow depths, while temperatures considerably lower than predicted may be encountered in deep formations.

It is obvious, therefore, that temperature extremes sufficient to preclude microbial activity are not likely to occur in those regions of the subsurface that are of greatest concern in regard to ground-water pollution, with the possible exception of a few regions of extreme geothermal activity and some very deep strata which may be employed for subsurface disposal of waste waters. In fact, the elevated constant temperatures of 25-40° C which are likely to occur in many subsurface regions would be ideal for growth of mesophilic organisms.

Hydrostatic pressure has been considered as a limiting factor on biological activity in the subsurface. The hydrostatic pressure within rock interstices, in which any subsurface microbial activity must occur, usually approximates the pressure which would be produced by a column of water extending from the surface to the depth of the measurement. Hence, interstitial hydrostatic pressure generally increases downward at an average rate of 0.1 atm per meter or about 0.43-0.47 psi per ft, although pressures considerably higher or lower than predicted may be encountered with some frequency (Russell, 1951; Cannon and Craze, 1938).

Hence, as Kuznetsov *et al.* (1963) concluded, hydrostatic pressure should not exceed 300-400 atm in the majority of subsurface regions where temperatures are not too high for microbial activity, although there may well be exceptions in regions of low geothermal activity.

Microorganisms differ considerably in their response to hydrostatic pressure. Most microbes which normally are found growing in habitats near atmospheric pressure appear capable of at least some growth at 200-300 atm at 30° C, although some species are completely inhibited or killed by these or even lower hydrostatic pressures (ZoBell, 1958; ZoBell and Johnson, 1949; ZoBell and Oppenheimer, 1950). At higher pressures the growth of organisms from surface or near-surface habitats is usually severely to completely retarded, and the survival of such microbes for significant periods at pressures of 500-600 atm is doubtful. On the other hand, many microorganisms isolated from deep sea habitats have exhibited the ability to grow readily at pressures above 400 atm during laboratory studies (ZoBell, 1970). These observations indicate that hydrostatic pressures are not likely to exclude microbial activity in subsurface regions which are otherwise suitable as microbial habitats. However, pressure in deep formations employed for subsurface disposal of liquid wastes may be sufficiently high to kill or to severely affect the metabolic activity of microbes from surface habitats which may be indigenous to the injected wastes.

Environmental factors other than those discussed above may also affect microorganisms in subsurface regions but do not seem likely to preclude microbial activity in such regions except in rare cases. For example, pH may limit the types of organisms which find various subsurface regions to be suitable habitats, and large solid surface areas characteristic of the highly structured subsurface environment may influence microbial activity through sorptive effects on extracellular enzymes, nutrients, and the microbes themselves.

It should also be noted that the various environmental factors, while discussed individually above, are interacting, as illustrated by the interrelation between temperature and pressure noted previously. Definitive experimental data concerning subsurface environmental factors are relatively scarce and incomplete and are not sufficient to define completely the total potential effect of these interacting factors on subsurface microbial activity. Nevertheless, available evidence indicates strongly that the upper continental crust of the earth is generally not a hostile environment for microorganisms.

For an active microbial population to develop, a microbial habitat must provide to resident microorganisms the nutrients which they require for synthesis of protoplasmic constituents and for generation of energy needed for conduct of life processes. For synthesis of protoplasm a carbon source, either carbon dioxide or organic matter, must be available, along with smaller quantities of nitrogen, phosphorus, and sulfur in either organic or inorganic form, and low levels of various minerals. Generation of energy by chemotrophic organisms (the absence of solar radiation obviously excludes phototrophs from subsurface environments) requires the availability of: (1) suitable electron donors, such as oxidizable organic compounds, or, for growth of chemolithotrophs, oxidizable inorganic substances such as molecular hydrogen, reduced sulfur compounds, ammonia, nitrite, and ferrous iron; and, (2) suitable electron acceptors including molecular oxygen, nitrate, sulfate, carbon dioxide, and simple organic compounds.

Potential sources of carbon for microbial utilization are relatively plentiful in many subsurface environments, since the upper continental crust of the earth is variously estimated to contain in the neighborhood of 10^{19}-10^{20} kg of carbon (Rubey, 1951; Alexander, 1971). Most of this carbon is present as inorganic compounds, principally carbonates, but an appreciable portion occurs as organic matter, much of which was incorporated into sedimentary deposits at the time of their formation and has not been completely mineralized over geological ages. Large quantities of organic compounds are found concentrated in petroleum deposits but vastly greater amounts are dispersed throughout sedimentary rocks in a finely disseminated state (Trask and Patnode, 1942; Trask, 1939).

Organic matter in sedimentary rocks may be grossly classified as bitumen, comprising organic substances which are extracted by neutral organic solvents, and kerogen, consisting of organic materials which are not readily soluble in such solvents. The bitumen fraction usually contains numerous hydrocarbon materials, fatty acids, porphyrins and many other substances; its composition is likely dependent to some extent on the organic solvent employed for extraction. The kerogen fraction constitutes the bulk of the organic matter in subsurface environments, usually comprising 90 percent or more of the total organic content of sedimentary materials (Davis, 1967). The composition of this fraction is very complex and subject to considerable variation; but, in general, it appears to consist in large part of humus-like materials.

A review of available data also indicates that essentially all subsurface waters probably contain significant quantities of dissolved organic matter (Dunlap and McNabb, 1973). This organic matter probably results both from leaching of organics from sedimentary rocks into ground water and transport of fresh organic matter from the surface by recharge water. Humic substances, naphthenic acids, fatty acids, and phenols are known to comprise part of the dissolved organic matter in ground waters near petroleum deposits, but the specific composition of the naturally occurring organic matter of ground waters generally remains largely unknown.

The growth of heterotrophic (chemoorganotrophic) bacteria may often proceed when very low levels of organic matter are available (ZoBell and Grant, 1942; ZoBell *et al.*, 1943). It would appear likely, therefore, that the organic substances present in most subsurface environments of sedimentary origin are sufficient in quantity to support microbial activity, both as sources of carbon for synthesis of protoplasm and as electron donors for generation of energy. However, microbial activity in the subsurface may be limited by the quality, rather than the quantity, of subsurface organic matter. For example, much of this material may, as noted above, consist of substances resembling soil humus components which yield to microbial degradative processes only very slowly, even under the most favorable conditions. Also, some compounds may not be utilized by microbes in the absence of oxygen per se (Alexander, 1965), and some may even be microbial inhibitors.

Carbon dioxide is potentially available as a carbon source for chemolithotrophic (autotrophic) microorganisms in many subsurface regions. Inorganic electron donors which might be oxidized by such microbes for generation of energy are also encountered with some frequency in subsurface environments. For example, molecular hydrogen is often present in subsurface gases (Kuznetsov *et al.*, 1963), and elemental sulfur and hydrogen sulfide are not uncommon in the earth's crust.

Nitrogen, phosphorus, and sulfur are probably present in essentially all sedimentary formations as constituents of organic and/or mineral matter, albeit the concentration of one or more of these elements, most likely nitrogen and phosphorus, may be extremely low in specific locations. However, since the amount of carbon in microbial protoplasm exceeds the quantity of nitrogen, phosphorus, and sulfur, respectively, by approximately five-, twenty-, and one hundredfold, and the latter elements are likely to be recycled in-place in subsurface environments, the levels of these elements required to maintain a minimum level of microbial activity in such environments would appear very low. Hence, it seems unlikely that nitrogen, phosphorus, and sulfur concentrations would often be so low in subsurface environments as to completely preclude all microbial activity, although the probability appears high that limited availability of one or more of these elements in a readily utilized form will restrict the level of microbial activity which can possibly occur in many subsurface regions.

Inhibition of microbial activity in subsurface environments solely because of unavailability of mineral elements would also likely be exceptional, since all subsurface waters are mineralized to some extent due to leaching of the rocks with which they come in contact, and the concentrations of inorganic ions required for microbial growth are usually extremely low. In this connection, Kartsev states that the presence of mineral compounds necessary for growth of hydrocarbon-utilizing microbes has been established in a wide variety of subsurface formations, although clay interbeds deficient in the minerals required for development of these bacteria have been observed in rare cases (Kartsev *et al.*, 1959).

Determinations of both molecular oxygen concentrations and oxidation-reduction potentials in subsurface environments are subject to formidable methodological problems because of the difficult accessibility of these regions. Consequently, definitive data concerning subsurface oxidation-reduction conditions are scarce. However, those data which have been reported, coupled with general observations concerning the probable availability and consumption (reduction) of molecular oxygen and other reducible substances in subsurface regions, provide a limited insight regarding probable oxidation-reduction conditions in subsurface zones.

In the zone of aeration, gas in the rock interstices is for the most part in direct communication with the atmosphere and, hence, is potentially subject to constant interchange with atmospheric gases. Interchange results from molecular diffusion of gases through the rock interstices and from actual displacement of interstitial gas due to diurnal heating and cooling of the earth's surface, changes in barometric pressure, and intermittent filling of interstices of gravitational water with subsequent displacement of this water by fresh atmospheric gas. It has been widely assumed, therefore, that high oxygen tensions generally prevail within the zone of aeration. However, the situation is probably not so simple as this assumption implies.

Regions of oxygen deficiency are known to occur with some frequency in the soil water subzone of the zone of aeration, even though oxygen replenishment by gas interchange should be most effective in this region by virtue of its close proximity to the atmosphere. These oxygen-deficient regions probably occur because of an unfavorable balance between oxygen replenishment by gas interchange, which appears to be restricted by interstitial spatial limitations, and oxygen utilization by soil microorganisms.

Microbial activity and, hence, oxygen consumption is almost certainly significantly less in the intermediate and capillary subzones of the zone of aeration than in the soil subzone in most situations.

However, the rate of gas interchange with the atmosphere must surely be related to depth and to permeability of the rock comprising the zone of aeration and is therefore likely to be low in these deeper regions, particularly in formations of low permeability. Also, the probability of survival of molecular oxygen during movement through the rock interstices towards the deeper regions of the zone of aeration could be relatively low if microbial activity in the soil zone were high. It would appear, therefore, that regions of oxygen deficiency may be at least as likely to occur in the deeper subzones of the zone of aeration as in the soil water subzone.

Oxidation-reduction conditions in the zone of saturation likely will reflect the balance between: (1) the rates of processes which result in the reduction of molecular oxygen and other reducible substances in ground water; and (2) the rates of entry into ground water of recharge water containing oxygen and other reducible substances and of diffusion into ground water of oxygen from the zone of aeration. Hence, redox conditions at any specific point in the zone of saturation will likely depend on (1) redox conditions in the overlying zone of aeration, (2) the distance from the air-water interface between the zones of aeration and saturation, (3) the level of microbial activity, (4) the rate of movement of ground water, and (5) the rate of ground-water recharge.

Since the deeper regions of the zone of saturation are far removed from the zone of aeration and the rates of ground-water movement within these regions and the rates at which they are recharged range from very low to essentially zero, it appears unlikely that appreciable oxygen and other easily reduced substances could be present in them. This supposition is supported by data obtained in the USSR during studies related to the genesis of and exploration for petroleum (Kuznetsova, 1960; Al'tovskii *et al.*, 1961).

On the other hand, considerable variations in rates of reductive processes and replenishment of oxidized substances appear possible in the upper regions of the zone of saturation. Hence, it seems likely that oxidation-reduction conditions in these regions may vary over a significant range of possibilities, although somewhat reducing conditions would appear to be generally favored.

The oxidation-reduction conditions in which microorganisms can grow have been cited by Vallentyne (1963) as ranging from an upper E_h limit of +850 mv at pH 3 for iron bacteria to a lower limit of −450 mv at pH 9.5 for sulfate bacteria. Limited observations of redox potentials in subsurface samples (Al'tovskii *et al.*, 1961; Stewart *et al.*, 1967) indicate that the total exclusion of microbial activity in subsurface environments by unfavorable oxidation-reduction conditions therefore seems unlikely, although the possibility exists that some deep regions of the zone of saturation might become so reduced as to preclude microbial growth. However, since different species of microorganisms usually are able to grow well only within a relatively narrow range of redox values, the oxidation-reduction conditions that prevail within a subsurface region will limit the species of microbes which may successfully inhabit that region and will often control the metabolic pathways and products of these microbes. For example, sulfate-reducing bacteria require an environmental E_h of −200 mv or less for initiation of growth (Postgate, 1959), and reduction of nitrate by facultative microbes in soil has been found not to proceed unless the redox potential is less than +338 mv at pH 5.1 (Patrick, 1960). Also, metabolic activity in soils apparently changes from aerobic to anaerobic, with concomitant accumulation of partially oxidized organic compounds, when the concentration of oxygen declines below 3×10^{-6} M (Greenwood, 1961).

Molecular oxygen, the electron acceptor required by obligate aerobes and usually preferred by facultative microbes, is undoubtedly absent from the deeper regions of the zone of saturation and is likely available in variable and often limited quantities in the upper regions of the zone of saturation and in the zone of aeration. However, other substances which serve as terminal electron acceptors for anaerobic organisms or which may be utilized as alternate electron acceptors by facultative organisms are widely distributed in subsurface regions. Sulfate, the required terminal electron acceptor of the obligately anaerobic sulfate-reducing bacteria, is probably present to some extent in most subsurface waters, often in relatively high quantity. Carbon dioxide, as previously noted, is present in many subsurface environments and may be utilized as terminal electron acceptor by several species of methane bacteria. Nitrate, the alternate electron acceptor for many facultative microbes, occurs often in subsurface waters, particularly at relatively shallow depths. Simple organic compounds which may serve a number of microbes as electron acceptors via fermentative metabolic pathways are also likely present in many subsurface environments, although such substances probably become progressively more scarce with increasing depth (Meinschein, 1971).

In total, the availability of electron acceptors is probably sufficient in many subsurface regions to support at least a minimum level of microbial activity. However, the rates at which electron acceptors can be replenished in various subsurface environments appear likely to limit the levels of microbial proliferation which may be sustained therein. Such replenishment rates are undoubtedly very low in many subsurface regions, particularly in deeper strata of the zone of saturation. Insufficient availability of suitable electron acceptors to sustain significant microbial activity may well be a principal factor in the survival for geological ages of organic matter, particularly petroleum deposits, in the earth's crust.

The observations presented in this section concern mostly subsurface environmental factors in natural environments unaffected by human activities. Unquestionably, such activities could profoundly alter the environmental conditions in many subsurface regions. For example, low levels of readily utilizable carbon sources, electron acceptors, and possibly phosphorus and nitrogen appear most likely to limit microbial activity in many subsurface environments. Disposal or groundwater recharge activities which result in the entry of liquid or solid wastes into regions below the soil zone would be likely to considerably alter this situation in the surrounding subsurface environment.

INVESTIGATIONS PERTAINING TO SUBSURFACE BIOLOGICAL ACTIVITY

Subsurface regions of the earth's crust have never been studied extensively by microbiologists. Early investigations by soil microbiologists on the distribution of microbes at different soil depths indicated the presence of relatively large populations near the surface with numbers decreasing with depth and attaining extremely low levels at the lower boundaries of the soil zone (Waksman, 1927; Waksman and Starkey, 1931; Alexander, 1961). From these studies, many microbiologists formed the assumption that biological life below the upper soil zone was either nonexistent or extremely limited. This assumption, when coupled with the immense technical problems and expense involved in subsurface investigations, resulted in many subsequent workers ignoring the subsurface as an area of investigation.

The problems involved in studying subsurface environments and the resultant expense have always been the main deterrent to subsurface investigations. Obviously, terrestrial environments far below the earth's surface cannot be directly examined because of their inaccessibility. Instead, biological activity in subsurface environments must be characterized by examining natural spring waters or by drilling wells and examining the resultant cores and well waters. Spring waters give an indication of the chemical nature of the producing aquifer, but are not necessarily biologically or chemically representative of deep stratal waters (Davis, 1967; Hem, 1959). In essence, they may provide meaningful information concerning the biological situation in the vicinity of the outcrop where the spring occurs, but are unlikely to accurately reflect microbial activity deeper within the aquifer formation.

Well waters are considered to provide more representative information concerning subsurface ecosystems than spring waters, but they are likely to reflect contamination resulting from drilling operations, and they may not be quantitatively indicative of the microbial population in an aquifer since the movement of water from the surrounding aquifer rocks into a well during pumping is likely to be much more rapid than the movement of microbes. Samples obtained aseptically from undisturbed cores undoubtedly provide the most representative information concerning subsurface microbial activity, but the acquisition of such samples is fraught with difficulties. Also, since subsurface strata are not homogeneous, both cores and water from a single well may not accurately reflect the microbial population of the adjacent rock formation.

Well drilling operations alter and contaminate the subsurface environment, especially with wells of any depth because of the need for circulating drilling fluids or muds to remove the cuttings and keep the walls of the borehole from collapsing. Drilling fluids often contain various sorts of additives and are a definite source of bacterial contamination (Davis, 1967; Smirnova, 1957).

The possibility that surface microbes can be introduced during drilling and sampling operations has caused many to question whether microbes isolated from subsurface samples were actually native to that environment. This has often been a valid question, particularly where samples were obtained from old boreholes or producing wells, since such samples are hardly representative of nondisturbed, uncontaminated formations.

Despite the possibility of contamination, many workers are convinced that uncontaminated samples can be and have been obtained from subsurface regions and, hence, microbes isolated from such samples are indeed native to the subsurface formations sampled (Davis, 1967; Kuznetsov *et al.*, 1963; Al'tovskii *et al.*, 1961; Beerstecher, 1954; ZoBell, 1958).

If an uncontaminated sample can be obtained, determining the number, type, and activity of any organisms present is also extremely difficult. The technical problems involved in such determinations have been discussed in detail by a number of microbial ecologists who all point out that it is presently impossible to accurately enumerate the microbial population of any ecosystem and measure the extent of its activity in the *in-situ* environment (Brock, 1966; Alexander, 1971; Hungate, 1962; Brock, 1971; Weibe, 1971).

Therefore, it must be understood that microbes found in subsurface samples may not give a true indication of the total microbial community existing in the sampled habitat and the processes occurring there. However, the repeated presence of certain microorganisms in samples from the same kind of habitat is highly indicative that they are native to that habitat and their metabolic capabilities provide some idea of their role there and the existing conditions.

A review of investigations pertaining to microbial activity in subsurface environments has been recently published (Dunlap and McNabb, 1973). Such investigations have proved beyond a reasonable doubt that many subsurface regions are not hostile to microbial life and, in fact, contain a varied and apparently active microflora.

Sulfate-reducing bacteria were the only microorganisms isolated in many initial studies because they were the only microbes which the experiments were designed to detect. Eventually, investigators examined the subsurface for other microbial groups and found a biochemically diverse microflora existing not only near petroleum and sulfur deposits, but also elsewhere in the subsurface. Various denitrifiers, methane formers, sulfur oxidizers, and hydrocarbon utilizers have been isolated, including members of the genera *Thiobacillus, Pseudomonas, Methanomonas, Mycobacterium, Actinomyces, and Pseudobacterium.* Although determinations of all numbers are inaccurate and undoubtedly do not reflect actual population densities in the *in-situ* environment, counts of several million bacteria per milliliter have been reported in some samples.

That sulfate reducers are not the only microbial group native to subsurface environments is illustrated by a study in which the pattern of distribution of hydrocarbon-oxidizing and gas-producing microflora within Pliocene and Paleocene deposits of the USSR was investigated (Bogdanova, 1966). Although both core and water samples were examined, the results from cores are most significant because the outer layer of each core was carefully pared off and only the theoretically uncontaminated interior of the core was examined. Hydrocarbon-oxidizing, sulfate-reducing, and methane-producing bacteria were found in cores of various types of sandstones, marls, and clays mixed with limestone, siltstone, and argillite from depths of 87-504 meters (285-1,654 feet). No apparent relationship between the distribution of various bacteria and depth was observed, and different types of microbes were invariably found in the same core sample. Only one of twenty-nine cores examined did not contain any microbes which could be detected by the methods employed.

The presence in subsurface environments of nearly all the organisms which have been reported as residing in such regions is not contraindicated by available knowledge concerning their physiological capabilities. Reviews on the ecology of sulfate-reducing bacteria point out that sulfate reducers, primarily the vibrio *Desulfovibrio desulfuricans*, are uniquely adapted to grow in subsurface environments, and it would not be surprising if they were almost ubiquitious in such regions (Kuznetsov, 1963; ZoBell, 1958; Postgate, 1959; Davis, 1967; Postgate, 1965). Sulfate-reducing bacteria are often found in association with other bacteria, a relationship which may be mutually beneficial (Kuznetsov, 1963; ZoBell, 1958; Davis, 1967). Ironically, sulfate reducers evidently are adversely affected by conditions such as high temperatures not directly inhibitory to them but which are inhibitory to associated organisms (Kuznetsova and Gorlenko, 1966).

In general, bacteria such as *Pseudomonas, Mycobacterium, and Actinomyces* species found in subsurface samples are also commonly found in upper soil layers. They are capable of growth in anaerobic environments by using nitrate or organic compounds as electron acceptors instead of oxygen. As a group they utilize a wide range of organic compounds as nutrients. A number of different species have been isolated from subsurface samples which in laboratory studies could oxidize hydrocarbons ranging from naphthalene to alkanes containing from one to ten carbons (Naumova, 1960; Telegina, 1961; Smirnova, 1961; Slavnina, 1965; Norenkova, 1966; Raymond, 1961). The number of compounds that organisms such as various *Pseudomonas* species are able to attack and degrade is vast, although they may be able to attack many substances only under aerobic conditions.

It is impossible to determine how long microorganisms have been in subterranean formations where they are found, especially since microorganisms isolated from such formations do not differ from surface microbes to any obvious extent. The microorganisms found in deep stratal waters may have been deposited with the sediments millions of years ago or they may have migrated into such strata from the surface over an undetermined period of time (ZoBell, 1958; Al'tovskii *et al.*, 1961; Reiser and Tasch, 1960; Messineva, 1962; Dombrowski, 1963). Bacteria are not only carried by underground waters moving through fractures, fissures, channels, solution cavities, and pore spaces, but they are also often able to propel themselves through water, perhaps to reach better conditions or to escape unfavorable environments. Such movement is extremely slow, ranging from a few microns to a few centimeters per day (Rose, 1968). It is possible that organisms could migrate outward from drilled wells over a period of years, contributing to colonization of some formations, since proliferation of microbes in the immediate vicinity of wells often causes severe corrosion and clogging problems (Davis, 1967; Baumgartner, 1962; Rebhun and Schwarz, 1968; Vecchioli, 1970). The extent to which such growth radiates from wells is uncertain, however.

DISCUSSION

The information obtained in the previous investigations of subsurface microbial activity clearly illustrates the presence of a diverse microbial population in many regions of the earth's crust lying below the soil zone. This information, in conjunction with available information concerning the suitability of subsurface environments as microbial habitats, indicates strongly that microbial activity is both possible and probable in most subsurface regions which are of importance in regard to ground water. The significance of such activity to ground-water pollution and pollution control, of course, resides in the potential interactions of pollutants and microorganisms in subsurface regions and the ultimate effect of such interactions on the quality and availability of ground water. Subsurface microbe-pollutants interactions are likely to be mainly beneficial, producing such desirable results as elimination of organic pollutants from subsurface waters by mineralization or removal of nitrate by denitrification. Such interactions might also sometimes be detrimental, resulting in production of undesirable metabolic products which enter and pollute ground water or reduction of aquifer permeability through clogging of interstitial space by cells and polymeric products of metabolism.

Previous investigations of subsurface microbial activity have been concerned primarily with delineation of the types and numbers of native microbes in essentially undisturbed subsurface environments, mostly in formations deep within the zone of saturation. These investigations provide a limited indication of possible microbe-pollutant interactions which might be expected to occur in some subsurface environments. However, they provide practically no information concerning: (1) the extent and nature of native microbial activity in the zone of aeration below the soil zone and in the upper regions of the zone of saturation; and (2) microbial activity in subsurface environments altered by the introduction of pollutants.

Microbial activity in the zone of aeration below the soil and in the upper portions of the zone of saturation is obviously of very great potential importance in regard to ground-water pollution and pollution control. Systematic studies to define the extent and nature of native microbial activity in these regions, correlating microbial data with environmental characteristics, particularly geological and oxidation-reduction conditions, are needed. These studies would provide data which would be useful in preliminary efforts to predict the fate of pollutants in these regions of the earth's crust, and which would serve both as a basis and complement to more extensive investigations pertaining to the movement, fate, and effect of pollutants in subsurface waters.

Microbial populations, and hence microbe-pollutant interactions, in subsurface regions receiving pollutants are likely to be profoundly affected by the nature and quantity of pollutants introduced and their effect on the native subsurface environment. For example, microbial species which are very minor members of the native ecological community may become dominant in the environment created by entry of pollutants. Also, microbes indigenous to the pollutant-containing waste introduced into a subsurface region may proliferate there, becoming the dominant species and controlling the fate of pollutants entering that region.

The above observations indicate the need for thorough, integrated investigations of microbe-pollutant interactions in subsurface regions receiving pollutants. *In-situ* investigations should be employed where possible, but laboratory simulation work utilizing core samples would probably often be required, particularly in the study of deep formations. Such studies should seek to correlate native microbial populations, environmental situations (geology, oxygen and nutrient availability, pressure, temperature, etc.), nature of pollutants, and microbial populations subsequently developing after the introduction of pollutants, with the fate of pollutants and their effect on ground-water quality and availability. Investigations of this type would necessarily be complex and expensive, but they would provide information needed in developing methods which would permit prediction of the probable impact on ground water of various activities entailing release of pollutants in to the earth's crust, including waste disposal, agricultural, and ground-water recharge activities, and which, therefore, would provide the basis for logical regulation and control of such activities. Such studies might also indicate how microbial activity in subsurface regions below the soil zone could best be managed and utilized to achieve maximum degradation of pollutants in subsurface waters. For example, improved knowledge of the factors controlling subsurface microbial activity might permit alteration of subsurface environmental factors and/or microbial populations to bring about mineralization of hydrocarbons or other organic compounds accumulating in aquifers as the result of accidents involving transport or storage equipment, or to achieve beneficial alteration of wastes intentionally introduced into deep formations.

CONCLUSIONS

Currently available information permits the following conclusions concerning subsurface biological activity in relation to ground-water pollution.

1. The upper continental crust of the earth comprises a highly structured and complex environment, characterized by limited open space and a myriad of environmental possibilities. In most subsurface regions, particularly those of sedimentary origin, these environmental possibilities do not appear so severe as to preclude microbial activity until depths are attained where temperatures exceed microbial tolerance levels. These depths are apparently in excess of 2,000 m in most regions.

2. Field investigations pertaining to subsurface microbial activity are difficult due to the inaccessibility of subsurface regions and the consequent difficulty in obtaining uncontaminated, representative samples from such regions. Nevertheless, a number of credible investigations reported in the literature clearly show the presence of diverse microbial populations in many subsurface regions lying below the soil zone.

3. Available information indicates strongly that microbial activity is both possible and probable in most subsurface regions below the soil zone which are of importance in regard to ground water. Hence, possible biochemical alteration of pollutants in these regions, as well as possible effects of pollutants on subsurface ecosystems, must be considered in attempting to control pollution of ground water.

4. Investigations to further elucidate the extent and nature of microbial activity in subsurface regions below the soil zone should be included in general studies pertaining to the movement, fate, and effect of pollutants in subsurface waters if these studies are to provide an effective basis for assessing the probable impact of human activities on the ground-water resource and for regulating and controlling the conduct of such activities to minimize the threat to ground-water quality.

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DISCUSSION

The following questions were answered by James F. McNabb after delivering his talk entitled "Subsurface Biological Activity in Relation to Ground-Water Pollution."

Q. by Mike Campbell. *In your investigations have you considered dissolved oxygen at levels of ppb, i.e. in deeper aquifers?*

A. There is a scarcity of information concerning the concentration of oxygen at which aerobic metabolic activities cease. Greenwood (1961) felt that metabolic activity in soils apparently changes from aerobic to anaerobic when the concentration of oxygen declines below about 0.1 ppm dissolved oxygen. What little evidence is available indicates that oxygen would not normally be present in the deeper regions of the zone of saturation in concentrations great enough to allow aerobic activity if one uses Greenwood's figure.

Q. by Steven Goldstein. *Could you comment on possible analogies with benthic (deep) marine microbiology—optimum growth at dilute nutrient concentrations, rise in dissolved oxygen at depth, etc.?*

A. Most studies concerning the effect of hydrostatic pressure on microorganisms have been conducted using microbes from deep marine environments. Except for high hydrostatic pressure and low oxygen concentrations, however, deep marine environments and deep aquifer environments are basically different.

Q. by Stephen E. Ragone. *Can microbes cause reactions to occur in the opposite direction to that predicted by the sterile circumstances—for instance, can sulfate be reduced by a "bug" in an oxidizing environment?*

A. The oxidation-reduction conditions that prevail within a habitat will control the metabolic pathways and products of various microbes. Sulfate-reducing bacteria require an environmental E_h of −200 mv or less for initiation of growth, for example.

Bacteriological Criteria for Ground-Water Quality[a]

by Martin J. Allen and Edwin E. Geldreich[b]

ABSTRACT

Although more than 60 million individuals rely upon the absence of microbial pathogens in their marginally-treated or untreated ground-water supplies, an analysis of reported waterborne disease outbreaks for the period 1946-1970 shows that contaminated ground-water supplies were responsible for over 50 percent of the outbreaks. Completed ground-water studies indicate: (1) coliforms and fecal coliforms are present in a significant percentage of improperly located or inadequately protected private supplies, and (2) the apparent absence of coliforms due to the insensitivity of currently available bacteriological methods does not preclude pathogen occurrences. Excessive bacterial populations, normally not encountered in finished water, can suppress coliform detection. For this reason, it is essential that improved bacterial detection methods be developed and other criteria for untreated ground water be explored by comprehensive field investigations and laboratory analysis of ground-water supplies for a variety of bacterial parameters.

INTRODUCTION

Ground water is used extensively as a source of potable water since: (1) in some areas surface supplies are insufficient, unavailable, or require extensive purification and treatment; and (2) ground waters are usually free of enteric pathogens. Some 180 million individuals are served by approximately 40,000 public water supplies (Table 1). Seventy-five percent of these public-water supplies use ground waters as a sole raw water source, and 7 percent of the public systems use a mixture of ground and surface waters (McCabe *et al.*, 1970). Private domestic water supplies, the vast majority of which rely on ground water, serve an estimated 33 million consumers.

In a survey of 969 public water-supply systems serving 18.2 million people, 613 systems utilized ground-water sources; 67 percent of this ground water was distributed to 2.8 million consumers without any disinfection (McCabe *et al.*, 1970). Further, those community water systems that used spring or mixed spring and well-water sources were found to have the poorest record in complying with the U.S. Public Health Service Drinking Water Standards. The poor water quality that these sources produced was attributed to both improper source protection and inadequate treatment. Thus, on a nationwide projection for marginally-treated public and private ground-water supplies, more than 60 million consumers rely upon the absence of microbial pathogens in ground water.

WATERBORNE DISEASES

An analysis of the numerous documented waterborne disease outbreaks that occurred between 1946 and 1970 indicates that contaminated ground waters were responsible for more than 50 percent of the 358 reported outbreaks and that over 40 percent of waterborne disease cases resulted from consumption of untreated ground water (Figure 1). Craun and McCabe (1973) attributed the high incidence (49.4 percent) of waterborne disease cases primarily to unsatisfactory well construction and improper

Table 1. Summary of Potable Water Usage

Type Water System	*Number of Supplies*	*Population Served (millions)*	*Percent Raw-Water Source*[1]		
			Surface	*Ground*	*Mixed*
Public	40,000[2]	180	18	75	7
Private (domestic)	15,000,000[3]	33	0	∿ 100	0

[1] McCabe *et al.* (1970).
[2] AWWA estimate.
[3] Todd (1970).

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[a] Presented at the Second National Ground Water Quality Symposium, Denver, Colorado, September 25-27, 1974.

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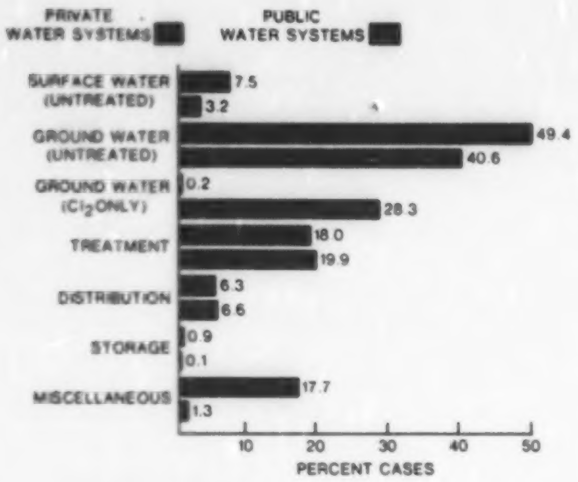

from Craun & McCabe

Fig. 1. Waterborne-disease cases in public and private water systems; percentage distribution by cause (1946-1970) (from Craun & McCabe, 1973).

location of wells. In public systems using ground water, however, both source contamination and treatment deficiencies were responsible for 95 percent of the cases of illness.

Specific waterborne disease outbreaks attributed to contaminated ground water include cholera, salmonellosis, shigellosis, infectious hepatitis, gastroenteritis, and amoebic dysentery. A comprehensive summary of the number of reported waterborne disease cases for the period 1946-1970 is presented in Table 2. Illnesses are grouped according to the etiological agent, i.e., bacterial, viral, protozoan. Although gastroenteritis accounts for a large percentage of cases in both private and public supplies, the specific causative agent for this illness is usually unidentified. In contrast to the high percentage (> 99 percent) of waterborne disease cases that result from microbiological contamination of water supplies, chemical-associated illness (excluding methemoglobinemia) from ground water are rare. Some of the chemical poisonings associated with ground water were attributed to improper injection of pesticides into shallow aquifers. Craun and McCabe (1973) further concluded that the inordinately high illness rate (i.e., waterborne disease cases per million per year) was from public systems delivering untreated ground water or either questionable source water quality or inadequately protected sources.

Table 2. Summary of Waterborne-Disease Cases (1946-1970) According to Type Illness and Water-Supply System*

	Water-Supply Systems		
Illness	*Private*	*Public*	*Total*
Bacterial associated:			
Typhoid	507	103	610
Salmonellosis	118	16,612	16,730
Shigellosis	1,616	5,784	7,400
Enteropathogenic *E. coli*	188	0	188
Leptospirosis	0	9	9
Tularemia	6	0	6
Gastroenteritis**	8,970	36,285	45,255
			70,198 (97%)
Viral associated:			
Infectious hepatitis	1,094	739	1,833
Poliomyelitis	0	16	16
			1,849 (2.6%)
Protozoan associated:			
Amebiasis	50	25	75
Giardiasis	19	157	176
			251 (0.4%)
Chemical associated***:	52	8	60 (0.08%)
	12,620 (17.4%)	59,738 (82.6%)	72,358

* from Craun and McCabe (1973).
** causative agent unknown.
*** methemoglobinemia not included.

More recently, bacterial pathogens including *Shigella flexneri, S. sonnei* and *Salmonella typhi* have repeatedly been isolated from well waters (Woodward *et al.*, 1974; Lindell and Quinn, 1973; Center for Disease Control, 1973, 1974) and poliovirus, an enterovirus, was isolated from well waters that had been consumed by restaurant patrons (VanderVelde and Mack, 1973).

BACTERIOLOGICAL QUALITY OF GROUND WATER

A high degree of correlation between the presence of coliforms and the occurrence of pathogens in surface water and water distribution systems has been firmly established (Geldreich, 1966, 1972). This same correlation has, in general, also been assumed to be valid for evaluating the potential health hazards of ground-water sources. Preliminary studies suggest, however, that the lack of demonstrable coliform levels in ground waters, partly because of microbial interferences and test media limitations, does not preclude pathogen occurrences (McFeters *et al.*, 1974; Boring *et al.*, 1971). A brief review of completed ground-water studies which include: (1) a survey of community water-supply systems, (2) Tennessee-Georgia rural water supplies, (3) Interstate Highway drinking-water systems (Kansas, Oregon, Virginia), and (4) Umatilla Indian Reservation ground-water survey, illustrates some bacteriological problems in ground waters (Table 3). In these four surveys, 9 to 51 percent of the samples examined contained coliforms and 2 to 27 percent of these same waters were positive for fecal coliforms.

Table 3. Microbiological Summary of Completed Ground-Water Surveys

Survey	*Number of Samples*	*Percent Coliforms**	*Percent Fecal Coliforms**
Community Water-Supply Study	621	9.0	2.0
Tennessee-Georgia Rural-Water Supplies	1257	51.4	27.0
Interstate Highway Drinking-Water Systems	241	15.4	2.9
Umatilla Indian Reservation	498	35.9	9.0

* 1 or more organisms per 100 ml.

Table 4. Bacteriological Quality of Raw Ground Water from Wells[1]

Coliforms[2]		*Fecal Coliforms[2]*		*Standard Plate Count[3]*	
Density	*Percent*	*Density*	*Percent*	*Density*	*Percent*
< 1	91	< 1	98	< 1	17
1-4	6	1-4	1	1-100	59
5-10	1	5-10	< 1	101-500	13
11-50	1	11-50	< 1	501-1000	4
> 50	1	> 50	< 1	> 1000	7

[1] from McCabe *et al.* (1970).

[2] per 100 ml.

[3] per ml.

Bacteriological data from the Community Water Supply Study (McCabe *et al.*, 1970) revealed that 9 percent of the 621 wells produced water that contained coliforms (Table 4); 2 percent of the same wells also contained fecal coliforms; 83 percent of the wells produced water that contained bacteria as determined by the Standard Plate Count (American Public Health Association, 1971); and 11 percent of the wells produced water that had bacterial densities greater than 500 organisms per ml.

Results from analyses of rural-water supplies in Tennessee and Georgia are presented in Table 5. Coliforms were present in approximately 50 percent of the domestic supplies and ranged from 1 to 54,000 organisms per 100 ml; fecal coliforms were present in 27 percent of the wells and ranged from 1 to 2,200 organisms per 100 ml. Whitsell and

Table 5. Bacteriological Summary of Tennessee-Georgia Rural Water-Supply Survey

Density	*Coliforms** *Number of Supplies*	*Percent*	*Density*	*Fecal Coliforms** *Number of Supplies*	*Percent*
< 1	633	49.5	< 1	940	73.5
1-10	68	5.3	1-10	73	5.7
11-100	151	11.8	11-100	113	8.8
101-500	142	11.1	101-500	67	5.2
501-1000	40	3.1	501-1000	20	1.6
1001-5000	110	8.6	> 1000	66	5.2
> 5000	135	10.6		1279	
	1279				

* per 100 ml.

Table 6. Bacteriological Summary of Drinking-Water Systems Along Interstate Highways (Kansas, Oregon, Virginia)

Density	*Coliforms**		*Fecal Coliforms**	
	Number of Samples	*Percent*	*Number of Samples*	*Percent*
<1	204	84.6	234	97.1
1-4	17	7.1	4	1.7
5-10	1	0.4	0	0.0
11-50	10	4.2	3	1.2
51-100	3	1.2	0	0.0
101-500	2	0.8	0	0.0
501-1000	2	0.8	0	0.0
>1000	2	0.8	0	0.0

* per 100 ml.

Table 7. Bacteriological Summary of Umatilla Indian Reservation Well-Water Survey

Density	*Coliforms**		*Fecal Coliforms**	
	Number of Samples	*Percent*	*Number of Samples*	*Percent*
<1	319	64.1	453	91.0
1-4	95	19.1	32	6.4
5-10	28	5.6	5	1.0
11-50	34	6.8	5	1.0
51-100	10	2.0	1	0.2
101-500	7	1.4	2	0.4
501-1000	2	0.4	0	0.0
>1000	3	0.6	0	0.0
	—		—	
	498		498	

* per 100 ml.

Hutchinson (1973) concluded that wells drilled in consolidated aquifers were more likely to yield water containing coliform bacteria than wells drilled in unconsolidated formations. Further, the high percentage of rural supplies contaminated with coliforms was attributed to inadequate sanitary safeguards and faulty construction practices.

In a study of drinking-water systems along Interstate Highways, 241 samples from 119 systems in Kansas, Oregon, and Virginia were analyzed (Table 6); there are an estimated 9,100 water-supply systems nationwide, including commercial facilities (service stations, motels, restaurants) and safety rest areas. The 119 systems examined included 106 with well distribution, 6 with hand pump wells, 2 with springs, and 5 with purchased finished water (Water Supply Division, 1973). Coliforms were detected in over 15 percent of the samples and fecal coliforms were present in 3 percent. Eight percent of the 114 systems were judged to have inadequate source protection, i.e., flooding of well pit or lack of sanitary well seal.

A fourth ground-water survey was completed at the Umatilla Indian Reservation located in the State of Washington. In cooperation with the Public Health Service, 498 well-water samples were examined for coliforms, fecal coliforms, and general bacterial densities (Table 7). The percentage of water samples that contained total coliforms and fecal coliforms was 35.9 percent and 9.0 percent, respectively.

In two of the above surveys (Interstate Highways, Umatilla), nearly 25 percent of the ground waters examined contained bacterial densities greater than 500 organisms per ml (Table 8); populations as high as 110,000 organisms per ml were noted. Although these general bacterial densities do not relate to a specific health hazard, elevated microbial densities can be associated with desensitization of standard coliform detection procedures (Geldreich *et al.*, 1972) and with the presence of a secondary human pathogen, *Pseudomonas aeruginosa;* this bacterium is often the cause of persistent ear and urinary infections (Hoadley, 1968; Whitby

Table 8. Comparison of Bacterial Densities and *Pseudomonas aeruginosa* Occurrences*

	Standard Plate Count (48 hrs. at 35°C)			
Density (per ml)	*Number of Samples*	*Percent Samples*	*P. aeruginosa Occurrences*	*Percent Occurrences*
<1	6	0.8	0	0.0
1-10	68	9.2	0	0.0
11-100	235	38.6	5	22.7
101-500	193	26.1	6	27.3
501-1,000	52	7.0	1	4.5
1,001-5,000	69	9.3	3	13.6
5,001-10,000	22	3.0	3	13.6
>10,000	44	6.0	4	18.2

* Umatilla and Interstate Highway Surveys.

and Rampling, 1972). Coliforms were not detected in 9 (41 percent) of the 22 ground-water sources that contained *P. aeruginosa* densities ranging from 1 to 2,300 organisms per 100 ml. Also, *P. aeruginosa* occurrences were often associated with excessive bacterial populations (Table 8). Similarly, Nemedi and Lanyi (1971) noted that over 50 percent of 227 potable-water samples from various sources that contained *P. aeruginosa* had no demonstrable coliforms and would be considered satisfactory on the basis of the coliform criterion. Twenty-one of 35 ground-water samples that contained *P. aeruginosa* had no demonstrable coliforms. Reitler and Seligmann (1957) examined 1,000 water supplies in northern Israel and concluded that varying populations of *P. aeruginosa* can interfere with the detection and/or enumeration of coliform bacteria.

BACTERIOLOGICAL CRITERIA

Presently, bacterial criteria for ground-water supplies are the same as those applied to treated potable water under regulations of the U.S. Public Health Service Drinking Water Standards (1962). These bacteriological standards limit total coliform densities in finished waters, including storage facilities and distribution networks, to less than one coliform per 100 ml. In the absence of suitable criteria for raw or marginally-treated ground waters from private systems, the same coliform standard has been routinely employed to assess the potability of these waters. Although total coliform bacteria are a valid sanitary index in finished water, their value as a sanitary quality standard in raw ground water has been questioned by various researchers. Results from ground-water surveys conducted thus far indicate that the coliform group may not be demonstrable by standard laboratory procedures in those water sources containing excessive bacterial populations. Under such circumstances, ground water that reportedly has low coliform levels as a result of test interferences could still pose a health hazard to those individuals consuming these waters.

For this reason, it is essential that improved bacterial detection methods be developed and other criteria for untreated ground water be explored. Such criteria are especially applicable to domestic ground-water supplies that are not routinely analyzed, infrequently serviced, and seldom disinfected. Confidence in any microbial indicator can only be established by comprehensive field investigations and laboratory analyses of ground-water supplies for a variety of bacterial parameters. Initial studies necessary to develop pertinent bacteriological criteria for these waters must first re-evaluate the sanitary significance of total coliforms in the ground-water environment. The presence and persistence of both total and fecal coliforms in water of varying hydrogeologic origin needs to be examined.

The sources of the total coliform group of bacteria include the feces of warm-blooded animals, the intestinal contents of cold-blooded animals, soils, and plants. Thus, total coliforms originate from a variety of sources and may be of limited significance in moderate densities (i.e., 1 to 10 organisms per 100 ml) in the ground-water microflora. In using the total coliform group as a quality criterion for ground waters, an appreciable number of supplies would be considered unsatisfactory for human consumption based on treated water limits, even though the total coliforms were from a non-fecal source, i.e., uncontaminated soils, plants. It is, therefore, desirable to implement bacteriological indicators that are more definitive in signaling fecal contamination and, consequently, potential pathogen occurrences.

More recently, fecal coliform occurrence has been considered more significant than total coliforms in evaluating the recentness of fecal contamination in water supplies. By elevating the incubation temperature from 35° C (the standard temperature for total coliform growth) to 44.5° C, much of the non-fecal coliform population is suppressed. An important advantage of the fecal coliform test is the ability to screen out those coliform bacteria that originate from soils and plants and therefore carry little sanitary significance. A distinct disadvantage of this procedure is that fecal coliforms can die-off at a greater rate than some enteric pathogens (McFeters *et al.*, 1974). More information is needed on survival patterns of all proposed indicator organisms and waterborne pathogens in ground water under different environmental conditions.

Another consideration in selecting bacterial quality criteria for ground water is the use of general bacterial densities. Waters from undisturbed aquifers, unlike those from surface sources, typically have low indigenous bacterial populations. However, in shallow aquifers where percolating water from surface sources can provide sufficient nutrients to support microbial growth, an unusually high bacterial population could indicate infiltration of contaminated water into the aquifer. More importantly, abnormally high microbial levels in shallow aquifers can adversely affect detection of the more specific bacterial indicators.

As described previously, excessively high microbial populations can influence survival and enumeration of the coliform group. Thus, coliforms could be undetectable in ground water where excessive bacterial densities occur. Also, the presence of *P. aeruginosa* can, under some conditions, suppress standard coliform enumeration procedures (Nemedi and Lanyi, 1971; Reitler and Seligmann, 1957). The failure to detect coliform bacteria results, unfortunately, in the assumption that these contaminated supplies are safe to drink. Therefore, it could be necessary to employ additional microbial indicator groups for ground water. These indicator organisms may supplement or replace the coliform group when ground-water conditions are such that erroneous results could occur.

Ideally, any bacterial indicator that is employed in assessing ground-water quality must be highly correlated with probable pathogen occurrences due to fecal contamination of the source. It is reasonable to select those groups of microorganisms that are indigenous to the microflora of warm-blooded animals; suggested groups other than coliforms have included *P. aeruginosa*, *Clostridium perfringens* (Bonde, 1962), *Bacteroides*, and the fecal streptococci that are known to be synonymous with fecal pollution and tend to parallel enteric pathogen persistence in the aquatic environment. Additional indicator groups, such as sulfate-reducing bacteria, could also be useful in measuring subtle ecosystem changes in overdeveloped aquifers. The increased occurrence of iron and sulfur bacteria in such aquifers could ultimately result in taste and odor problems that reduce the desirable aesthetic qualities associated with high-quality potable water.

Finally, there is a critical need to establish sanitary guidelines to ensure the quality of ground-water resources during site selection, drilling, well construction and finishing, usage, and eventual rejuvenation or abandonment. These guidelines must be applicable to both the water well contractor and the well owner/user. Specific concerns include the inadvertent contamination of the aquifer by nuisance microorganisms during drilling (i.e., slime, iron-precipitating, sulfate-reducing bacteria) and the infrequency of bacteriological and chemical analyses of water from producing wells. It is important to stress to the consumers of domestic ground water that a single satisfactory water analysis of a newly completed or rejuvenated well will not ensure a permanently safe supply. Although consumption of contaminated ground water does not always result in an outbreak of a specific waterborne disease, such water can produce sporadic subclinical gastroenteritis which can ultimately reduce an individual's natural resistance to disease.

Current agricultural, industrial, waste disposal, and land-use practices that could ultimately affect the potability of ground-water resources are of continuous concern to those who rely upon these source waters. The impact of the injection of high-quality waste effluents into aquifers for later withdrawal needs to be extensively studied; such effluents could degrade ground-water quality by providing nutrients necessary for bacterial growth. The effect of surface and near-surface activities on future ground-water quality must always be paramount because once an aquifer has been contaminated, it is exceedingly difficult and sometimes economically unfeasible to reclaim it.

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DISCUSSION

The following questions were answered by Martin J. Allen after delivering his talk entitled "Bacteriological Criteria for Ground-Water Quality."

Q. by Mike Campbell. *What criteria were used for selecting the communities for the EPA drinking-water study?*

A. The selection of communities for the drinking-water survey was based on: (1) defined metropolitan communities that include large cities and their satellite urban areas; and (2) geographic spread throughout the country.

Q. by Leonard Halpenny. *How about viruses in water from wells?*

A. The only documented viral occurrence in ground water was published by VanderVelde and Mack, J. Amer. Water Works Assoc. 1973, 65(5)345-348. The authors reported isolation of poliovirus from well waters which had been contaminated by wastewater.

Q. by Robert Mutch, Jr. *Does fecal strep or the fecal coliform/fecal strep ratio have value in the determination of ground-water pollution as they do in surface-water pollution studies?*

Q. by Bill Pitt. *Many investigators are suggesting the use of a fecal strep to fecal coliform ratio as a better indicator of fecal contamination. How do you feel about this?*

A. Fecal coliforms appear to be a better indicator of low level fecal contamination in ground water. Fecal streptococci densities below 100 organisms per 100 ml are generally *Streptococcus fecalis* var. *liquifaciens* which is ubiquitous in the environment (ref. Geldreich and Kenner, Concepts of Fecal Streptococci in Stream Pollution, 1969. J. Water Pollution Control Fed. 41(8), Part 2, R336-R352.) and therefore carries little sanitary significance when present in ground waters.

Q. by Bill Weist, Jr. *Do you have any data relating the occurrence of the bacteria found to the depth of the well or to the method of well construction?*

Q. by Dave Johe. *In your analysis, no mention was made as to the number of drilled vs. dug wells. Can you elaborate? Were not most of the contaminated wells dug or improperly constructed drilled wells?*

A. Whitsell and Hutchinson (1972) concluded from information obtained from studies on rural water supplies that: (1) there exists a correlation between the method of well construction and bacterial contamination of the water (i.e., driven and drilled wells are less susceptible to contamination than bored or dug wells); (2) drilled wells in consolidated aquifers are more likely to yield contaminated water than those drilled in unconsolidated formations, and (3) for all type wells, the protection of ground water from contamination is related to adequate casing and grouting measures.

Q. by Henry Trapp, Jr. *Why were not Federal Drinking Water Standards set up to protect the travelling public, applied to rest-stop water supplies on Interstate highways?*

A. The Federal Highway Administration requires that water systems at safety rest areas along Interstate highways be designed, constructed, and maintained in accordance with State health regulations. Thus, the State government agencies are primarily responsible for monitoring of these water systems. State health regulations do specify that these water supplies meet the bacteriological standards defined in the Federal Drinking Water Standards.

Q. by Darrel Primeaux. *Why are ground waters from consolidated aquifers more apt to contain coliform contamination than ground waters from unconsolidated aquifers?*

A. Consolidated aquifers, particularly limestone and dolomite, yield a significant percentage of water through fractures, joints, and solution channels. The permeability of such aquifers is basically a function of secondary openings which readily accept and transmit infiltrating waters. When hydrogeologic conditions allow for contaminated water to enter openings in these aquifers, little filtration of pollutants occurs in or along the fractures. Subsequently excessive pumping facilitates rapid movement of the contaminated water and can also result in induced infiltration of contaminated surface sources.

Q. by Don Rima. *In view of the many opportunities for contamination to occur at the point of withdrawal, why are you suggesting that the aquifer is contaminated when samples are found to contain bacteria?*
A. Typically, undisturbed or protected aquifers yield water containing low indigenous bacterial populations. Ground or well waters that contain excessive bacterial populations and/or fecal-associated microorganisms are indicative of contamination by inadequately filtered infiltrating waters.

Q. by Don Keech. *(a) Can you explain why food processing wastes, i.e. cherry wastes, have a high fecal coliform count, often over 10,000/100 ml? (b) Were wells resampled that showed coliform counts during the surveys?*
A. (a) Food processing wastes can contain excessive fecal coliform densities since: (1) some raw food stuffs are contaminated with animal fecal material (bird droppings), and (2) food processing plants can provide warm temperatures and nutrients (carbohydrates) necessary for the growth of coliform bacteria. (b) Wells that were positive for coliforms (total, fecal) were not resampled.

Q. by Jack Kooyoomjian. *Have you been working on viral, in addition to, bacteriological relationships for ground-water quality? If not, are there any plans to examine viral criteria in the near future?*
A. To date, no virological studies on ground-water sources have been completed by this agency. Current virology efforts are on raw surface-water sources used in water treatment and on finished water quality. Although there are no plans to examine ground water for viruses in the immediate future, there is no reason that such a survey could not be initiated if epidemiological data indicate an increasing problem with enteric viruses in these water sources.

Q. by Charlie Nylander. *Have any of the nitrifying and denitrifying bacteria been used as indicator organisms? What is the potential for using these organisms for domestic wastewater contamination?*
A. Neither nitrifying nor denitrifying bacteria have been used as indicator organisms in assessing the potability of ground water although denitrifying bacteria have been isolated from ground waters. There appears to be little potential in using either group as indicators of fecal contamination, but these groups might be useful as indicators of ecosystem changes and chemical contaminants from leachates.

Q. by G. Meyer. *What steps were taken in sampling to insure representative ground-water samples? Who are the sampling authorities? Is not sampling a tricky business?*
A. Ground-water samples were collected according to procedures in the *Manual of Individual Water Supply Systems*, 1973, EPA-430-9-73-003, pg. 137. Sampling authorities in the studies reported were sanitary engineers of Water Operations Programs and their Regional Water Supply Representatives. Sample collecting is not tricky but must follow a specified protocol to obtain a representative sample.

Q. by Marv Sherrill. *There is some thought that even though total coliforms in the ground water may not indicate pathogens they do indicate essentially nonfiltered organisms from the near-surface—please comment.*
A. The presence of the total coliform group of bacteria in ground water indicates the infiltration of bacteria-laden surface or near-surface waters. Thus, while coliforms do not always imply fecal contamination of the source water, their presence indicates a break through of organisms from surface drainage, fecal or nonfecal.

Q. by James Pool. *Injection and recovery of fresh waters and treated sewage effluent in saline aquifers holds much promise for certain areas of the Gulf Coast. Would you recommend that careful determinations of the influence of subsurface bacteria on these injected waters be done before injection is allowed? Also, could subsurface bacterial action destroy or greatly reduce the usefulness of the injection waters for reuse?*
A. Injection of sewage effluents into aquifers requires high-quality effluent with continuous chlorination. Systems should be under continuous monitoring for bacteriological quality and disinfection efficiencies. The injection well needs to be incorporated with fail-safe design so that in case of chlorinator failure or inadequate chlorination, contamination of the aquifer will not occur.

Natural Soil Nitrate: The Cause of the Nitrate Contamination of Ground Water in Runnels County, Texas[a]

by Charles W. Kreitler[b] and David C. Jones[c]

ABSTRACT

The ground waters of Runnels County, Texas, are highly contaminated with nitrate. The average nitrate concentration of 230 water samples was 250 mg/l NO_3.

The natural variations of the stable nitrogen isotopes N^{14} and N^{15} identified natural soil nitrate as the predominant source. Nitrate from animal wastes was of minor importance. The δN^{15} range of natural soil nitrate was +2 to +8 ‰, whereas the δN^{15} range of animal waste nitrate was +10 to +20 ‰. (Atmospheric nitrogen was used as a standard for mass spectrometric analysis. Experimental error for sample preparation and isotopic analysis was ±1 ‰.) More than 60 percent of the ground-water nitrates analyzed were in the δN^{15} range of natural soil nitrates.

Dryland farming since 1900 has caused the oxidation of the organic nitrogen in the soil to nitrate. Minimal fertilizer has been used because of the lack of suitable water for irrigation. During the period 1900-1950, nitrate was leached below the root zone but not to the water table. Extensive terracing after the drought in the early 1950's has raised the water table approximately 6 meters and has leached the nitrate into the ground water. Tritium dates indicate that the ground water is less than 20 years old.

INTRODUCTION

Nitrate contamination of the ground water of Runnels County, Texas, was first recognized in July of 1968 after several cattle died of anoxia from drinking the water containing excessive nitrate concentrations. Subsequent analyses indicated that 88 percent of the 230 water wells sampled contained ground water with nitrate concentrations over the U.S. Public Health Service recommended limit of 45 milligrams per liter (mg/l) as nitrate. The average nitrate concentration was 250 mg/l with a range of less than 1 mg/l to over 3,100 mg/l.

High nitrate waters were not restricted to aquifers directly beneath areas of concentrated animal wastes (e.g., barnyards or septic tanks), but were found also in pastures and cultivated fields. The probable sources initially considered were nitrate from animal wastes and nitrate from the oxidation of natural soil nitrogen due to cultivation. Nitrogen fertilizer was not considered a probable source because the lack of acceptable quantities of ground water prevented extensive irrigation and the concomitant use of fertilizers.

GENERAL DESCRIPTION OF RUNNELS COUNTY

Runnels County is located in west-central Texas and has an area of 2,741 square kilometers (1096 square miles) (Figure 1). The Colorado River (of Texas) flows west to east through the southern half of the county; the topography is flat to gently

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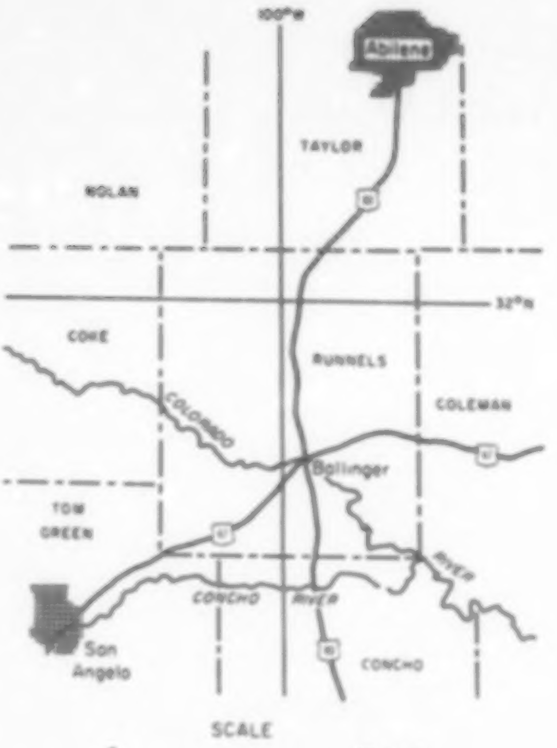

Fig. 1. Location of Runnels County, Texas.

rolling. The soils are classified as mollisols (prairie soils with high organic matter) (Wiedenfeld and others, 1970) or Chesnut soils (Millar and others, 1958) depending on the classification used. The average rainfall is 580 mm (23 in). The economy is based on the production of cotton, wheat, sorghum, corn, cattle, hogs, and sheep.

HYDROGEOLOGIC SETTING

South of the Colorado River, ground water is pumped from shallow Permian carbonate aquifers of the Wichita-Albany and Clear Fork Groups. North of the Colorado River, ground water is pumped from Tertiary and Quaternary calichified gravels as well as from the Permian carbonate aquifers.

Significant ground-water flow is restricted to solution cavities along bedding plane surfaces, joint surfaces and solution cavities in the dense limestone beds, and to noncalichified sections of the gravels. Analyses of 3 aquifer pump tests in the limestones yielded transmissivities of 1.0 cm^2/sec, 21.9 cm^2/sec, and 9.7 cm^2/sec, and coefficients of storage of 4×10^{-4}, 5×10^{-6}, and 4×10^{-4}, respectively. One aquifer pump test in the gravels indicated transmissivity of 119 cm^2/sec and a coefficient of storage of 1×10^{-3}. Well yields are generally less than 6 l/sec (100 gpm). Few wells are deeper than 30 meters.

Ground-water flow is toward the Colorado River in both the northern and southern parts of the county except in the extreme south where flow is toward the Concho River.

DETERMINING THE SOURCE OF NITRATE

The source of nitrate in certain natural systems (for example, Runnels County) can now be identified by correlating the natural nitrogen isotope ratios (N^{14}/N^{15}) of ground-water nitrate to the nitrate in soils of different land-use environments. Previously, the tracing of nitrate in natural waters to its original nitrogenous source (whether it was fertilizer, cattle waste, septic tank effluent, sewage treatment effluent, or natural soil nitrogen) was an extremely difficult task. The very soluble nature of the nitrate ion permitted easy migration away from its source and was commonly separated from other identifiable tracers.

A 3-step nitrogen isotope study was devised to determine the sources of nitrate in Runnels County: (1) develop reproducible methods of analysis; (2) delineate unique isotopic ranges for nitrate from different soil environments; and (3) compare the nitrogen isotope ratios of ground-water nitrate to isotopic ranges of soil nitrate to determine the predominant source. Kreitler (1974) and Jones (1973) discussed in greater detail the various aspects of this program.

Methods of Analysis

The stable isotopes of nitrogen are N^{14} and N^{15} of which N^{14} predominates; 99.632 ± 0.002 percent of nitrogen in the atmosphere is N^{14} (Junk and Svec, 1958; Nier, 1955). In other nitrogenous compounds, these percentages vary slightly because of isotopic fractionation. The variations of mass are measured on a gas-source mass spectrometer in which the sample is compared to atmospheric nitrogen, the standard. The ratio of sample to standard is expressed in the accepted isotopic terminology as:

$$\delta N^{15}(‰) = \frac{(N^{15}/N^{14})_{\text{Sample}} - (N^{15}/N^{14})_{\text{Standard}}}{(N^{15}/N^{14})_{\text{Standard}}} \times 1000$$

If N^{15} in the sample is enriched relative to N^{15} in the atmospheric nitrogen standard, the sample has a positive δ value; if relatively depleted in N^{15} the sample has a negative δ value.

For isotopic analysis nitrate must be converted to nitrogen gas. Nitrate (NO_3^-) is reduced to ammonia (NH_3) with Devardas Alloy, and then distilled in a basic solution. The ammonia is oxidized to nitrogen gas with sodium hypobromite. The nitrogen gas is then purified by vacuum circulation through a Cu-CuO furnace followed by circulation through a liquid nitrogen cold trap, thereby eliminating carbon dioxide, carbon monoxide, nitrous oxides, water vapor, and oxygen. The gas is analyzed by comparing the ratio of mass 29 to mass 28 ($N^{15}N^{14}/N^{14}N^{14}$). The analytical techniques are modifications of Bremner and Keeney (1966), Hoering (1955), and Myaka and Wada (1967).

Soil samples (1 to 2 kg) were collected every foot to depths of 1.5 to 3 m (5 to 10 ft) from 15 holes drilled with a rotary air drilling rig. Samples were stored in an air conditioned room (25°C) before the summer of 1973, and in a freezer locker at a meat packing plant (below 0°C) from the summer of 1973 until the fall of 1973. No attempt was made to adjust the soil moisture content or to heat the soils as is done in soil incubation studies.

Samples were leached overnight with deionized or distilled water. After decanting the clear liquid, the soil slurry was centrifuged for maximum recovery of the nitrate solution. The nitrate was then analyzed isotopically by the technique previously described.

The validity of this study depends on both accuracy and precision of the values obtained for δN^{15}. First, the measurement of nitrogen isotopes with the mass spectrometer must be demonstrated to be correct; second the techniques used for sample collection, storage, and preparation must be both accurate and precise.

The precision of the mass spectrometer and thus the precision of the standard was determined by comparing four atmospheric nitrogen samples to another atmospheric sample. An 0.27 ‰ variation was detected among samples collected at different locations and at different times.

The accuracy of the mass spectrometry was determined by analyzing Mathewson pre-purified tank gas previously analyzed by Junk and Svec (1958). The average atmospheric nitrogen sample (Ames, Iowa air) of Junk and Svec (1958) was 3.01 ‰ heavier than their Mathewson pre-purified nitrogen tank gas. Atmospheric nitrogen from Austin, Texas, was 2.87 ‰ to 2.92 ‰ heavier than the same Mathewson pre-purified nitrogen tank gas used by Junk and Svec in 1958. This is a difference of only 0.11 ‰, which is within the precision of the mass spectrometer. It is assumed, therefore, that the standards used in this study are accurate.

To check the reproducibility of the sample preparation techniques, 10 samples of $NaNO_3$ solution and 7 samples of NH_4Cl solution were analyzed. The NH_4Cl samples had a mean δN^{15} of +1.22 ‰ with a standard deviation of 1.06 ‰. The $NaNO_3$ samples had a mean δN^{15} of +1.04 ‰ with a standard deviation of 0.59 ‰. Experimental error is approximately ±1 ‰.

The reproducibility of δN^{15} values of soil nitrate could not be determined by running duplicate analyses because the soil samples, in general, did not contain enough nitrogen for more than one analysis. However, the consistency of δN^{15} values with depth in a soil profile (Figure 2) and the consistency of δN^{15} values between a soil stored unfrozen (profile a) and a soil stored frozen (profile b) in Figure 2 shows that the analysis of soil nitrate is reproducible. The data, therefore, is considered correct, and the observed isotopic variations are due to natural isotopic fractionations and not to experimental error.

δN^{15} of Nitrate in Differential Soil Environments

The soil-nitrogen environments studied were barnyards (4 sites, 12 samples), septic tank drain fields (2 sites, 4 samples), cultivated fields where cattle had never been grazed (4 sites, 15 samples),

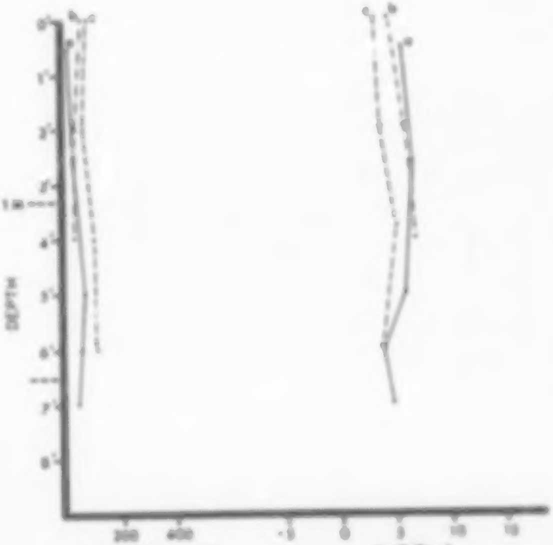

Fig. 2. Nitrate and δN^{15} versus depth beneath cotton fields with no animal wastes. Samples from profile a stored unfrozen. Samples from profile b stored frozen.

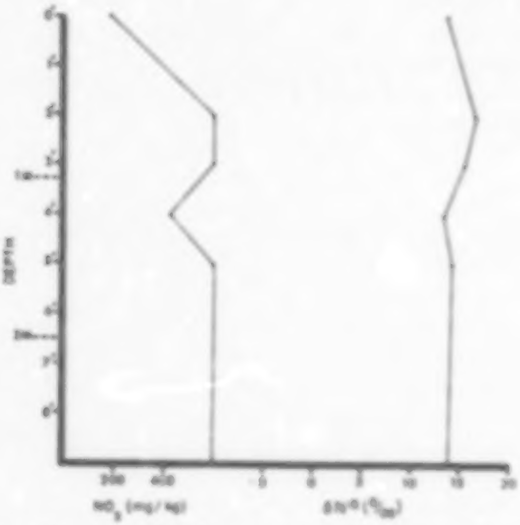

Fig. 3. Nitrate and δN^{15} versus depth beneath barnyard with definite animal waste contribution.

cultivated fields where cattle had grazed (2 sites, 6 samples), and turnrows (narrow dirt roads between cultivated fields used to bring farm equipment to the fields and as turning areas for tractors) between cotton fields (2 sites, 11 samples). Soils treated with artificial fertilizers were not considered because of their low usage in Runnels County. The 15 sampling sites (48 samples) were located in as wide a geographic area as possible and in as many different soil associations so that the δN^{15} ranges would represent the average for the area.

Nitrates in Soils from Barnyards and Septic Tank Laterals

Figure 3 compares δN^{15} and nitrate concentrations of a barnyard soil at various depths. The value of δN^{15}, approximately +14 ‰, remains relatively constant with depth. The nitrate concentrations are high, similar to other nitrate profiles of barnyards from this study (Jones, 1973).

The δN^{15} values and nitrate concentrations from 5 other barnyards (Figure 4) are consistent with the δN^{15} values of Figure 3. Figure 4 also shows the δN^{15} and nitrate concentrations of soils in septic tank drain fields. The δN^{15} values of these soils are greater than +10 ‰.

The frequency distribution curve on the right side of Figure 5 shows the δN^{15} range of nitrate from barnyard and septic tank drain field soils in southern Runnels County, Texas.

Nitrates in Soils from Cultivated Fields and Turnrows with No History of Cattle

Figure 2 compares the δN^{15} and nitrate concentrations in soils from various depths in cotton fields where livestock have never grazed. These soils have low nitrate concentrations and lower δN^{15} than the δN^{15} of barnyard or septic tank nitrate. There is no apparent correlation of δN^{15} with nitrate concentrations, soil type, or geographic distribution of cotton field soils.

Figure 6 shows the δN^{15} and nitrate concentrations in soils from turnrows where cattle have never grazed. These soils have similar δN^{15} values

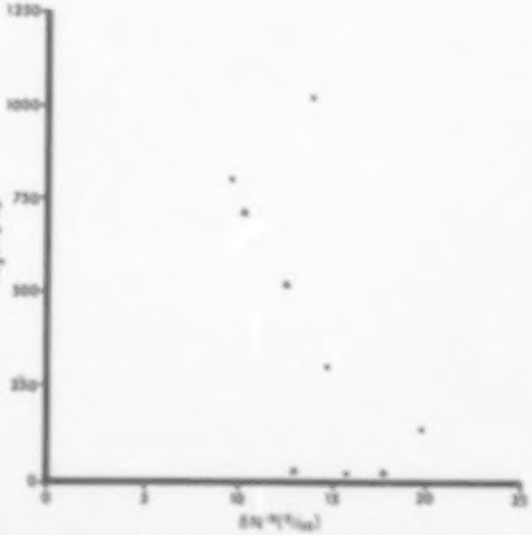

Fig. 4. δN^{15} and nitrate from barnyards (●) and septic tank laterals (▲).

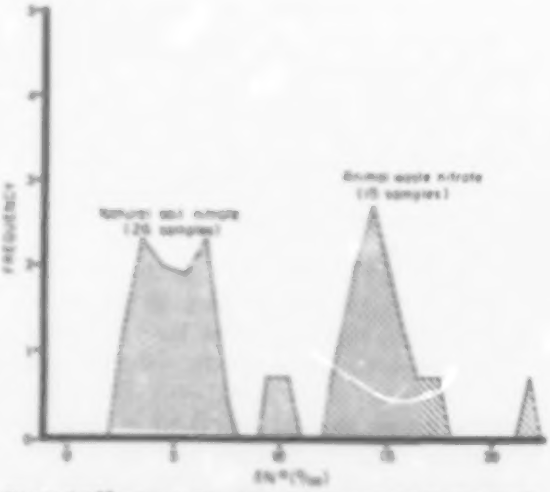

Fig. 5. δN^{15} ranges of natural soil nitrate and animal waste nitrate. Frequency polygons have a class interval of one δN^{15} unit. Cumulative frequency of each curve is equal to 1.0.

but higher nitrate concentrations in comparison to cultivated fields with no history of cattle. The difference in nitrate concentrations of the turnrow soils and the cultivated field soils reflects the complete lack of plant growth on the turnrows in contrast to the nutrient assimilation by crops in the cultivated fields. In the planted fields, some of the soil humus is annually oxidized to nitrate which is assimilated as plant nutrient. In the turnrow soils there is no utilization of the nitrate by plants, thus nitrate concentrations are high. In both turnrow profiles, the δN^{15} remains constant with depth and is within the same range as the δN^{15} of nitrate in soils from cultivated fields, even though the nitrate concentrations vary greatly.

The curve on the left side of Figure 5 is the frequency distribution of δN^{15} in the cultivated fields with no history of cattle and the turnrows with no history of cattle. These environments produce a lower isotopic range than the barnyard and septic tank soils.

Nitrates in Soils from Corn Fields with Grazing Cattle

Figure 7 is a δN^{15} – NO_3 profile below a corn field where cattle have grazed on corn stubble. The owner could not remember how long cattle had grazed in this field, but he had a "feeling" that it was for the past 10 to 20 years. This profile shows lower δN^{15} values with depth, but constant nitrate concentrations, indicating that the dominant source of nitrogen had changed with time. The δN^{15} of nitrate from shallow depths is within the range of animal waste material, whereas the δN^{15} in the deeper portion of the profile is within the range of natural soil nitrogen. The higher values represent nitrate accumulation during the years when cattle grazed on the corn stubble, whereas the lower δN^{15} represent nitrate accumulation during the years before the cattle were grazing on this field.

The soils which have a known source of nitrate can be divided into 2 categories: (1) soils with animal waste material as a dominant nitrate source, and (2) soils with a natural soil nitrate source with no contribution from animal waste material. These isotopic ranges do not overlap. Soils from fields with grazing cattle would be expected to have δN^{15} values between the δN^{15} of nitrate of animal wastes and the δN^{15} of natural soil nitrate, reflecting a mixing of nitrates from the 2 sources.

δN^{15} of Nitrate in Ground Water

The δN^{15} of nitrate from 31 different water samples from water wells in Runnels County, Texas, was determined. The water wells selected for sampling have large geographic distribution, high and low nitrate concentrations, and different local land use, e.g., wells in cotton fields and wells in barnyards. Samples were collected from 5 wells in barnyards, 12 wells near farm houses, 2 wells in pastures, and 11 wells in cultivated fields away from sources of animal waste.

A plot of the ground-water nitrate concentrations versus δN^{15} shows a wide spread of δN^{15}

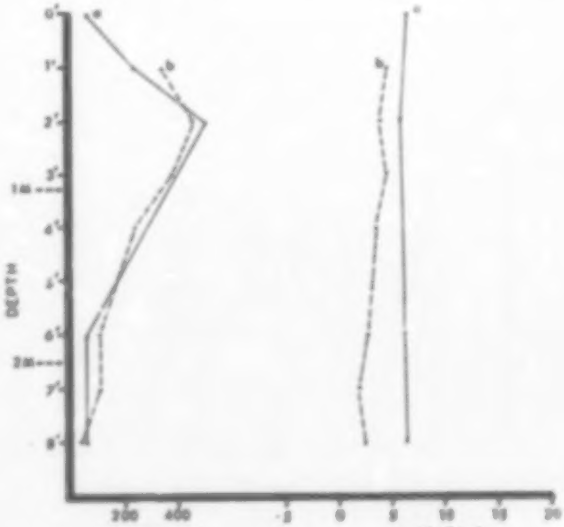

Fig. 6. Nitrate and δN^{15} versus depth beneath turnrows with no animal contribution of N.

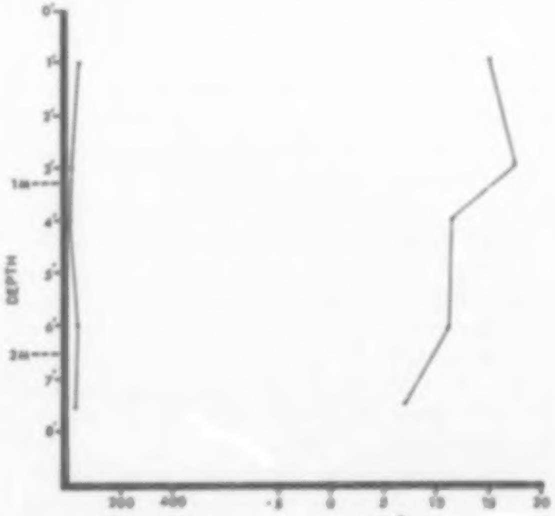

Fig. 7. Nitrate and δN^{15} versus depth beneath corn field with grazing cattle.

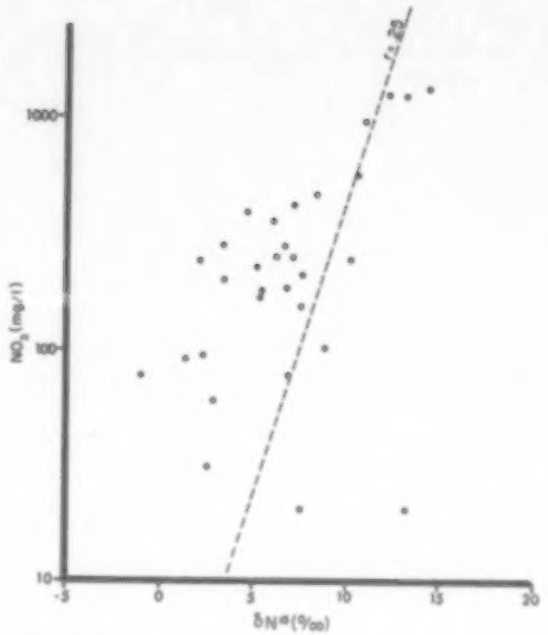

Fig. 8. δN^{15} of nitrate in ground water from Runnels County, Texas.

values with only a small correlation (r = 0.25) of δN^{15} with the nitrate concentrations (Figure 8). The ground waters with the highest NO$_3$ concentrations have the most enriched δN^{15} values. However, even the waters with low δN^{15} values have nitrate concentrations which exceed the limit recommended by the U.S. Public Health Service. With a linear correlation of nitrate and δN^{15}, one source of nitrate would be predominant. High nitrate concentrations with both high and low δN^{15} values indicate that there are at least 2 sources in the samples analyzed but the sources or their relative importance cannot be determined with this graph.

A comparison of the δN^{15} of nitrate in ground waters under specific land-use areas, for example, barnyards and cotton fields, with the δN^{15} of the nitrate from different soil environments identifies the 2 sources and shows their relative contribution. By overlaying a frequency distribution graph of δN^{15} in ground waters beneath cultivated fields with no cattle on the graph of 2 δN^{15} soil nitrate ranges, there is a remarkable coincidence between the δN^{15} of natural soil nitrate and the δN^{15} of ground-water nitrate (Figure 9).

An overlay of the frequency distribution of δN^{15} of ground-water nitrate from wells near farmhouses, but not in barnyards, on the 2 δN^{15} soil nitrate ranges shows an isotopic shift toward the animal waste nitrate (Figure 10). The predominant source in this case is still nitrate from cultivated fields because the average δN^{15} of the ground-water nitrate is below +9 ‰ (the average of the means of the 2 isotopic ranges).

The frequency distribution of δN^{15} of ground-water nitrate from barnyard wells shows a wide range of δN^{15} values, indicating that both natural soil nitrate and animal waste nitrate are contaminating the ground waters beneath barnyards (Figure 11). The predominant source of nitrate in ground waters beneath barnyards may depend on the influence of the regional hydraulic gradient and on the pumping history of the barnyard well. The 3 high δN^{15} samples are from barnyard wells located on topographic highs. The potentiometric surface generally follows the topography. Ground-water flow, and thus nitrate migration, should be away from the barnyard rather than toward it. The soil and water samples from a hilltop farm illustrate this point (Table 1). The farmhouse-barnyard complex is at the top of a slight hill and the direction of ground-water movement should be downslope. The soil and water samples from this barnyard are enriched in δN^{15}. A water sample from a field well downslope from the farmhouse-barnyard complex is also enriched in δN^{15}. On the other side of the hill, the shallow water table intersects the land surface forming a seep where continual evaporation of ground water precipitates nitrate which is also isotopically heavy. Movement of nitrate is away from the barnyard and toward the field because of its topographic position.

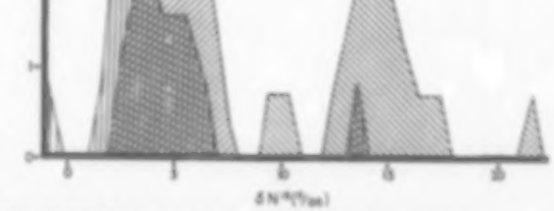

Fig. 9. δN^{15} of nitrate in ground water from wells in cultivated fields compared to the δN^{15} of natural soil nitrate and animal waste nitrate.

Table 1. δN^{15} of Nitrate from Ground Water and Soils of Hilltop Farm

Source	δN^{15} (‰)
House well	+14.1
Barnyard well	+10.4
Field well	+13.1
Barnyard soil (depth 1 m)	+14.6
Septic tank drainfield (depth .7 m)	+10.3
Septic tank drainfield (depth 1 m)	+12.4
Soil seep	+ 9.8

The 2 barnyard water samples (Figure 11) with low δN^{15} values are on slopes. Water wells would be pumping, in part, ground waters that had been recharged upslope. Therefore, barnyard wells could be pumping ground waters with natural soil nitrate rather than ground waters with animal waste nitrate.

The δN^{15} of ground-water nitrate from wells in barnyards may also be related to how often a well is pumped. If a well is not pumped frequently, the major nitrate source may be animal waste. Frequently pumped wells will create cones of depression and draw ground water from a more extensive area than just beneath the barnyard. Much of the nitrate in these ground waters may be from natural soil nitrogen. Of the 3 high δN^{15} samples, 2 wells had been pumped infrequently over a period of one year. The samples with lower δN^{15} values were from wells that are pumped daily.

DISCUSSION

Figures 9, 10, and 11 demonstrate that the δN^{15} of the ground-water nitrate can be used to identify sources of NO_3 in Runnels County, Texas. The 2 sources are natural soil nitrogen, the predominant source, and animal waste nitrogen. The relative contribution of each source can be calculated by making certain assumptions and by comparing the ratio of acreage for different land uses. The assumptions are: (1) 20 percent of the ground-water nitrate beneath farm complexes originates from animal waste material, whereas 80 percent originates from natural soil nitrogen (Figure 10 shows that the source of nitrate beneath the farmhouse-barnyard complexes is predominantly natural soil nitrate); (2) the volume of ground water per unit area is the same under farmhouse-barnyard complexes as under cultivated fields; (3) the nitrate concentrations in the ground water are relatively constant under both conditions; (4) the total area of an average farm is 400 acres, of which the farmhouse-barnyard complex occupies 2 acres. The acreage producing nitrate from natural soil nitrogen is 200 times greater than the acreage producing nitrate from animal wastes, and only 20 percent of the nitrate in the ground waters beneath the farmhouse-barnyard complexes is from animal wastes. The estimated contribution of nitrate from soil nitrogen is then 1,000 times greater than the nitrate contribution of animal wastes.

To use natural soil nitrogen as a source of nitrate contamination for Runnels County, 3 additional problems must be considered: (1) Was there enough organic nitrogen in the original soils to account for the nitrates in the ground water?

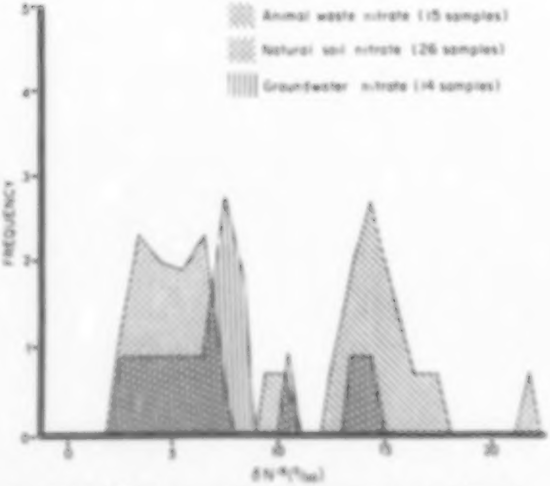

Fig. 10. δN^{15} of nitrate in ground water from wells near farmhouses, but not in barnyards compared to the δN^{15} of natural soil nitrate and animal waste nitrate.

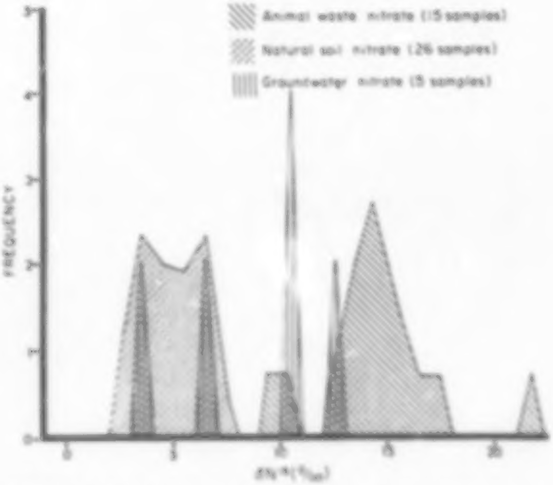

Fig. 11. δN^{15} of nitrate in ground water from barnyard wells compared to δN^{15} of natural soil nitrate and animal waste nitrate.

(2) When was the organic nitrogen oxidized to nitrate? (3) When was the nitrate leached below the root zone and then leached into the ground water?

(1) The total organic nitrogen in the original soils can no longer be determined because the soils have all been cultivated for the last 50 years. The soil type, texture, type of vegetation, and rainfall regime of Runnels County, however, imply that the original total nitrogen must have been high.

Schreiner and Brown (1938) found that different soil types had different total nitrogen concentrations. Chernozem, Prairie, and Chesnut soils have high concentrations (0.12%, 0.12%, and 0.08%, respectively), whereas soils in progressively wetter or drier climates have progressively lower concentrations of nitrogen. In the wet climates, the soil organic matter is rapidly mineralized and leached. In the desert climates there is inadequate plant growth to develop much soil organic matter. The semiarid climate [510 to 640 mm (20-25 in) of rain per year] provides a happy medium between increased plant growth and minimal decomposition and leaching. The soils in Runnels County, Texas, are Chesnut soils (Millar and others, 1958) or mollisols (Wiedenfeld and others, 1970) which form under average rain of 360 to 610 mm (14 to 24 in). Oxidizing 50 percent of the nitrogen in these soils would theoretically create nitrate concentrations of at least 500 mg/kg.

Before 1900, Runnels County was covered with buffalo grass, which favored a high nitrogen content in the soils. Soils under grasslands develop higher nitrogen concentrations than similar soils beneath forests. As annual grasses die, their roots are rapidly added to the soil humus, whereas in forests, the root systems do not decay annually, nor do they occupy such a large fraction of the soils volume as the grass roots (Villenski, 1957).

The nitrogen content also is related to the clay content. Soils with high clay content can have much higher nitrogen contents (Millar and others, 1958). The texture of the soil in Runnels County is typically clay loam or silty clay loam.

(2) The oxidation of soil nitrogen has been occurring since the first days of cultivation. After 1900 there was a steady immigration of European farmers to Runnels County. The farmers put nearly every arable acre into crop production. The high nitrate concentrations of the turnrow soils are probably the result of the oxidation of natural soil nitrogen and the lack of nitrogen assimilation by plants over the 50 to 70 years of cultivation. The amount of nitrate in these soil profiles is consistent with the amount of nitrate that can be oxidized from the organic nitrogen in a Chesnut soil in the same time period. Reinhorn and Avnimelech (1974) use a similar model of oxidation of soil nitrogen as a source of high nitrates in a coastal aquifer in Israel.

(3) The problem of determining when the nitrates were leached below the root zone and into the ground water has not been completely resolved. Nitrate at shallow depths in cropland soils will be assimilated by plants; thus, for nitrate to be a potential ground-water contaminant, it must first be leached below the root zone and then leached to the water table. Nitrate has probably been accumulating below the root zone since 1900. The winter fallow season permitted both the generation and the leaching of nitrate. The amount of winter rains was adequate to leach nitrate below the root zone.

In the mid 1950's there was extensive terracing of the fields to improve retention of soil moisture. According to many of the farmers, the water table rose appreciably, more than 6 meters in some places. The increased infiltration of water and the ground water which rose to near the ground surface, leached the nitrates from the vadose zone into the ground water. Tritium analyses indicate that the nitrates were leached into the ground water after the drought of the early 1950's. Using tritium dating techniques of Dincer and Davis (1968), ground waters from 4 of the deepest wells in the county were dated at 13 to 17 years old, 8 to 13 years old, 9 to 12 years old, and 16 to 19 years old, relative to 1974. These samples, which represent the deepest ground waters in the area, are all post-terracing waters, thus the leaching also appears to be post-terracing.

The nitrates in the ground waters of Runnels County are the result of the oxidation of part of the humus of semiarid grassland soils and the subsequent leaching of the nitrate to the saturated zone by extensive terracing in the 1950's. This conclusion is disturbing because there are no inexpensive measures which would alleviate the problem. Contamination of the shallow ground water is ubiquitous in the cultivated areas of the county and is not restricted to halos surrounding animal waste sources. However, most of the nitrate may have been leached away by the rising ground water. Analyses of ground waters over a 3-year period show an apparent gradual decrease in the nitrate concentration. Even if this trend continues, though, it will be many years before the nitrate concentrations are reduced to U.S. Public Health Service recommended limits of 45 mg/l.

CONCLUSIONS

(1) Nitrogen isotope ratios of nitrate ions from soil and water samples can be analyzed reproducibly with an experimental error of ±1 ‰.

(2) There are 2 isotopic ranges of soil nitrate in Runnels County, Texas. Nitrate derived from the decomposition of animal waste nitrogen yields a δN^{15} of +10 ‰ to +22 ‰. Nitrate derived from the mineralization of organic nitrogen in soil humus has a δN^{15} of +2 ‰ to +8 ‰.

(3) In Runnels County, Texas, the major source of nitrate in the ground water is natural soil nitrate. The δN^{15} of the ground-water nitrate beneath cultivated fields corresponds well with the δN^{15} of natural soil nitrate. Ground water beneath farmhouse-barnyard complexes has a higher δN^{15}, indicating a contribution of animal waste nitrate. Ground water from wells in barnyards has a wide range of δN^{15} values.

(4) The natural soil nitrate in the ground water is the result of cultivation which causes the oxidation of some of the organic nitrogen to nitrate. Natural soil nitrogen may contribute as much as 1,000 times more nitrate to the ground water than animal wastes. Extensive terracing during the 1950's in Runnels County caused the water table to rise, allowing the ground water to leach the soil nitrate into the aquifer system.

(5) The identification of the source of ground-water nitrate in Runnels County, Texas, indicates that the techniques developed in this study are applicable for identifying sources of nitrate in other polluted waters.

ACKNOWLEDGMENTS

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DISCUSSION

The following questions were answered by Charles W. Kreitler after delivering his talk entitled "Natural Soil Nitrate: The Cause of the Nitrate Contamination of Ground Water in Runnels County, Texas."

Q. by B.P.C. Sinha. *Could nitrate in rain water contribute to high nitrate ground waters?*
A. Junge (1958) found that neither nitrate or ammonia concentrations were more than 1 or 2 mg/l. This source is insignificant to the amount of nitrogen in soil humus.

Q. by D. D. Runnells. *Is there any isotopic fractionation of N by ion-exchange in soil or dissolving of ammonia in water?*
A. Isotopic fractionation of nitrate in high anionic soils is relatively small. Delwiche and Steyn (1970) found an approximate 2 ‰ fractionation of nitrate on an anion exchange resin. High anion exchange soils would not be expected to be found in pedocal soils either. Kirshenbaum *et al.* (1947) measured a 34% fractionation between gaseous ammonia and ionic ammonium at equilibrium. This is an important fractionation controlling the nitrogen isotope range of animal waste nitrate.

Q. by M. Campbell. *What special techniques were used for ground-water sampling?*
A. Nearly all water samples were collected from pumps already on the wells. Frequently pumped wells were used in preference to wells rarely used over the previous years. For those wells where no pump was available, samples were bailed.

Q. by R. G. Kazmann. *Would you recommend reverse osmosis to produce drinking water cheaply?*
A. A private company tried this technique for a single farm. The average nitrate from the farmer's well was 1000 mg/l. They found that reverse osmosis was too expensive.

Q. by G. M. Powell. *Did you make any mass balance of total N in ground water?*
A. No. For one, total N was not a problem, because organic nitrogen, ammonium and nitrite were generally very low. A mass balance of the nitrate was not determined either, because we did not know the total volume of the aquifers (either the gravels or the limestones) nor know enough about the porosity (especially the limestone aquifer).

Bull Session — The Impact of Zero Discharge Legislation on Ground Water

Session Moderator: Kent Ballentine, U.S. EPA, 4th and M Streets, Washington, D.C. 20460.

Kent Ballentine, Moderator: This is the Bull Session on The Effect of Zero Pollutant Discharge on Ground Water. I have put out some extracts from the Federal Water Pollution Control Act of 1972. This extract is my idea of the requirements of the legislation that talks about zero discharge. In addition, I have 2 reports that EPA has put out in compliance with the Act. One of these is "Evaluation of Land Application Systems," which is a draft report prepared by Metcalf and Eddy, Consulting Engineers. I don't think it's available for distribution yet but it's out in draft form. The other describes the Best Available Treatment (BAT) requirements put out this past March for comments and it's not out as a final document yet. It is entitled "Alternative Waste Management Techniques for Best Practical Waste Treatment."

As a review of the legislative history of the Federal Water Pollution Control Act, it should be pointed out that the earlier versions required the EPA to evaluate land disposal as the primary method of treatment and then conventional treatment as an alternative. In the version that was finally passed, it does not specifically mandate that, although the legislative history does indicate this was Congress' intent. So, with these few comments and the extracts from the legislation, we might as well open this session up. The way it was expressed today was that the results from this group would express people's feelings about the concepts of zero pollution discharge. Is there a viable alternative, or is it technologically unfeasible?

Kenneth E. Webb, Colorado Department of Health, 4210 E. 11th Ave., Denver, Colorado 80220: Under the 201 facilities plan, we have some environmental organizations and also professional people in the State of Colorado who think the way to achieve zero discharge is to apply secondarily-treated effluent to land surfaces, either for purposes of irrigation or as advanced waste treatment. I think that application is a viable alternative; I think it is extremely site selective; I think it must be very well engineered and even operated much better than most of the advanced wastewater or secondary wastewater treatment plants are operated. If it isn't, I think we've swept our problems under the rug. I don't know who it was that decided that we had to consider land treatment as an alternative. That's like saying that you have to consider activated sludge or a physical-chemical treatment process. Why they singled out one particular method is beyond me because I think it has led to some misunderstanding by people who aren't well informed about the situation, and being concerned about the quality of ground water, I'm concerned about 201 requirements and the zero discharge statement or goal in the Act. What I'm saying is that we have groups in Colorado who say, "This is the way to go. If we spread it on the alfalfa field, it's zero discharge." I don't personally agree with that, but these are environmental groups, and they are very persuasive and influential.

Kent Ballentine: Of course, this process ignores the hydrological facts that the base flow of most streams is ground water, and when you get polluted ground water, you subsequently get polluted surface water.

Kenneth Webb: Well, although Colorado doesn't have a lot of surface water, we do have the Colorado River. But as you fly over Colorado, you're not going to see big rivers like you have in the eastern U.S. Nevertheless, it's a fact of life that our communities were settled along what little water there is. Most of our communities on the East and West Slopes were settled along the South Platte, Arkansas, Rio Grande, San Juan and the Colorado. Since the towns are there, naturally the sewage treatment plants are along the rivers and most of your treatment plants are in the flood plain. If we would go to land treatment, in all probability that land treatment is going to be over an alluvial aquifer. This really worries me. We've got a thousand square miles of pasture out there in eastern Colorado where you can discharge secondary effluent and it would not contaminate ground water but unfortunately, it's going to cost a bundle of money to pump it out there.

Kent Ballentine: I'm not familiar with western water law, but what does that do to your appropriated water rights?

Kenneth Webb: That's a good question. This is something that we have to consider. If you change the point of discharge, you're looking at Colorado water law, you might have to buy water rights to replace, or you might have to trade off. In other words, there would have to be a legal arrangement or you could be in violation of State water laws. In other words, land treatment is not God's answer to what our problem is. It represents many problems.

Norman Lovejoy, Nelson, Haley, Patterson and Quirk, Inc., 102 N. Cascade, Suite 202, Colorado Springs, Colorado 80902: I'm a project director on a 208 study and I'm looking for help. The question of zero pollutant discharge is an extremely serious one in Colorado and particularly in our 208 area because of the requirement that some of the flow be returned to the stream. There's just no way out of it that I see. I'm not a lawyer and I hate to make a statement as arbitrary as that, but we have irrigation ditches that are located right at the point of the effluent discharge of existing plants who have great seniority. So, there's no way that you could do it without buying that ditch company out, and it would cost more than the tertiary plant. Does zero pollutant discharge mean that the water has to be drinking water quality? I'm looking for guidance on what is meant in terms of the zero pollutant discharge for that portion of the flow which must be returned to the stream. There's no alternative to it, because of western water law, unless we change the constitution of the State of Colorado.

Kent Ballentine: One thing to remember is that zero pollutant discharge is a goal. It doesn't say it's mandated. It's just a goal to move in that direction. I don't think the agency has really defined zero pollutant discharge, and I don't think they're able to at this time, and this is the kind of forum in which they'd like to gage the public's reaction.

Norman Lovejoy: Perhaps we should direct this discussion at the impacts then of the zero pollutant discharge: the social, economic and institutional impacts, so that we can get a better idea of the meaning of the loopholes in the Act. What are some of the impacts that go into a zero pollutant discharge? Institution is one. In any area you have the conflict—Chicago has already experienced this—between the rural area who sees the sludge and the city. Are institutional impacts an excuse? No. Are they a basis for exemption?

Arnold Schiffman, Water Resources Administration, 580 Taylor Ave., Annapolis, Maryland 21401: Is the term "zero pollutant discharge" or "zero discharge"?

Kent Ballentine: It's "zero pollutant discharge." As you look in the Act there at Section 101(a)(1), it states that the national goal is that the discharge of pollutants into the navigable waters be eliminated by 1985.

Arnold Schiffman: Who is defining—pollutants can be anything, right?

Kent Ballentine: Well, if you look at the last page of that handout, there is a definition. Congress has defined pollution and the term pollutant as pretty much anything that does not have to do with oil and gas production.

Arnold Schiffman: I think the subject of this session is the effect of zero pollutant discharge on ground water. Since this country as a whole basically deals with surface water, maybe it would be helpful to look at the concepts of surface water, which are very disturbing when applied to ground water. First of all the concept with the streams. The old concept was that you could put waste into streams which have a certain assimilative capacity. That's a dirty word now. Now we're looking at an effluent limit on the goal toward zero discharge. The effluent limit is based on protecting in-stream uses including the fish, etc. If you look at water supply, as we're going to look at ground water, you basically look at increasing or improving treatment technology. All right, we apply these same concepts to ground water. For one thing, there are no in-stream ground-water uses.

Kenneth Webb: Of course there are in-stream ground-water concepts.

Arnold Schiffman: Well, maybe you can invent some. It's not in-stream ground-water uses in the same sense as in-stream surface-water uses, which effluent standards are designed to protect. What I'm afraid of is that to a lot of people outside this room, there is no such thing as ground-water pollution. You can extend it even further. For example, if you look at use, I guess ground water has 2 basic uses. One is water supply, the other is assimilating waste water. If you look at the water-supply angle, is ground water polluted if you put something in it and there isn't a well field producing water from it? Is there ground-water pollution?

What I'm saying is that inside this room it's fine, we all know what the story is. But outside of this room, I think there could be a very good case made by saying that there is no such thing as ground-water pollution. There are no in-stream uses as most people would recognize them. And as for water supply, if it's not affecting a well field, as far as anybody is concerned, nothing has happened. Of course, we can go and delineate polluted areas; we can put in test wells; we can collect samples, etc., and show that there has been a change in ground-water quality. The concept of zero pollutant discharge can go for both air quality, I guess, and surface-water quality. That implies or strongly suggests that it is the national policy to degrade ground water. We have to figure out what is pollution of ground water. I guess if we use "water supply" we can define it as Drinking Water Standards. I guess some people might have the idea that that's the best ground-water standard. There's an awful lot of ground water of higher quality than Drinking Water Standards; so, if we're going to protect the streams, not degrade them at all, not degrade the air quality, by definition we are now talking about degrading ground-water quality.

Norman Lovejoy: But EPA in that regulation they issued August 27, recognized ground water as a significant source to be protected. That's the first time I've seen ground water recognized as a significant source and to be inventoried and protected.

Arnold Schiffman: Treating ground water on the same level as surface water and air quality is incompatible with the Federal program, unless you go through some complete recycling. I'm saying by definition we are now going to degrade ground-water quality.

Kenneth Webb: Well, I think your concern is the same as my concern, because I can see a tendency for people to say, "We'll go to secondary treatment, but if it requires better than that, we'll just put it out on the ground and raise crops with it," and of course we've got a 90-120-day growing season, so what are we going to do with the other 8 months out of the year? I'm concerned that some of our heavy metals, our nitrates and so forth are going to leach into the ground water.

Kent Ballentine: What would be the difference, assuming that over the winter you'd have to store water? Many of your sugar companies do that already, right? They store in lagoons, and then they can release it when the streams open in the spring. Don't you get a certain amount of infiltration under those conditions?

Kenneth Webb: I think probably we do. The thing that I object to is endorsing land treatment as a cure-all for advanced waste treatment because I think if we do that, we're going to sweep our problems underground. It's going to degrade the ground water. We have documented cases—a documented case here in the South Platte basin which the NWQA did back in 1967.

Kent Ballentine: Of course, EPA has had some problems with their nondegradation policy for surface waters because it's almost impossible to have any kind of economic development at all without degrading surface-water supplies slightly.

Kenneth Webb: My idea is that even if you only have secondary treatment, you put that effluent into the stream, in Colorado at least, it's going to go on down the stream, and if that thing is full of nitrates, in all probability you're not going to degrade anybody's well field to be used for municipalities. It's going to go downstream and be diverted for agriculture, irrigation purposes and spread on the field, and it may or may not find its way back into the hydrological cycle. However, if you've got a land disposal system over here and those nitrates leach into that ground water, I'm not at all sure at what point in time or if ever, that stuff is going to come back in and be surface water. It's extremely site selective. I am not 100% against it. I think there are places where it will work, but the way the Mineral Act and the other Acts read, I'm afraid people are going to have a tendency to sweep the problem under the rug.

Norman Lovejoy: They'll be required to meet the law. They'll be required to finish the study based upon certain criteria and they'll dump it upon the land to get rid of it to meet the law. So, that's the danger to ground water.

Kent Ballentine: Which guidelines are you reading here, are you referring to the BPT or BAT?

Norman Lovejoy: Well, the whole set of circumstances.

Kenneth Webb: I'm specifically referring to your 201 guidelines. What's the policy goal that is in section 101, the preamble to the '72 amendments?

Unknown Speaker: Is ground water going to be the victim of all of this because it's not specifically spelled out in the Act as a navigable waterway? Or is there a way we can look at the waste water as a part of our total resources, as a part of the total resource system? Then we end up back with the recycle question.

Kent Ballentine: Of course, I think if you read through the goals, the idea of recycling was also inherent in the Act and this is what Congress was trying to encourage. I don't think it's deliberately laid out in the Act that we're going to pollute ground water rather than pollute surface water or deteriorate air quality or anything else. I would say that the possibility of ground-water pollution was probably more of an oversight than anything else. If you look at the history of land disposal, much of it came from some of the Corps of Engineers studies. I think they had done some studies that indicated that land treatment was desirable, especially in areas where ground-water levels were declining severely. EPA has probably considered one of the areas in Florida where there is planning for the use of secondary effluent for recharging ground water—either to avoid salt-water intrusion or to raise the water table.

Unknown Speaker: The nitrate question I think came up after the initial Corp of Engineers studies. Is the nitrate question being blown out of proportion?

Paul Plummer, Miami Conservancy District, 38 E. Monument Ave., Dayton, Ohio 45402: Well, I think the nitrate question is a western problem. We're not worried about nitrates in the East.

Arnold Schiffman: We're worried about it to protect stream quality, not—in many cases, in the quality-limited streams, the nitrate standards would be lower than Drinking Water Standards, say 3 parts versus 10. If you put the stuff on the ground, the loading is going to be the same, except maybe for some losses. It's going to be moving to the stream anyway. So, we may be self-defeating on our stream standards.

The other thing is, we are talking about waste water. There's no such thing as waste water. We have wastes, water used as a transport medium, so what are we doing? We are taking the stuff out of the transport medium, we do something with the transport medium, and we still have a whole bunch of stuff, whether it be municipal treatment sludge or worse yet, the industrial sludges that we're creating. So, we're not just talking about diverting the waste source from the streams to the land, we're concentrating it and putting it on the land. All the industrial sludges that are being formed—the States and the Federal government are cleaning up the surface waters in this country. They're doing it and they're doing a good job. But they're removing the stuff from the water, which is the transport medium. They have to pile it, then. I don't know if anyone else knows where it goes. There's all sorts of strange things in that industrial sludge. Municipal sludge, we know. I think everybody has a handle on it. At least we know it goes on the land.

We've arbitrarily said that we're going to let one resource take the brunt, even though the Act doesn't say that, that's what it does. We should look at a problem and say, "Okay, with this waste, how do we treat it, what's the cheapest way, and where do we put it?" Maybe it's better to go into the stream; maybe it's better to go into the air, maybe it's better to go into the land. But those choices are not being made. By definition, it's better to go into the ground.

David Johe, Ohio EPA, 361 East Broad St., Columbus, Ohio 43215: I think I have a good case in point. One of the problems that we are currently faced with is air quality standards. As a result of these, both federal and State, the power plants are being required to install lime scrubber systems to remove SO_2 from the air. Now, in our situation, these plants exceed the air quality standards only a few days a year. But these scrubber systems have to operate 365 days a year. As a result of this, we are creating literally billions of tons of calcium sulfate, which is going to be deposited anywhere the utility can get away with it. As I understand it, for every ton of coal that is burned, there will be half a ton of sludge produced. Now, this is a monumental problem as we see it. If you could operate these scrubbers only on the days that they were exceeding standards it would be one matter. But, they have to operate them year around.

Kent Ballentine: Let me ask you to comment on this one item. I was talking to a colleague of mine who is a microbiologist, and he was saying that there are certain areas of the country now where with the new regulations limiting SO_2 and other sulfur fumes, that they're running into sulfur deficiencies now in soils. And they're having to consider adding sulfate now to fertilizer, where they didn't have to in the past, because enough rained out from air pollutants. Would there be any market for that calcium sulfate by adding it to fertilizer compounds to make up for such a deficiency?

David Johe: I don't think so–that is, we don't have a sufficient market for it. This might take care of some small amounts.

Frank Titus, Ebasco Services, Inc., 21 West St., New York, New York 10006: We in Ebasco have an environmental study. Considering your suggestion that these sludges could be put to a use of this sort, let me point out that along with the sulfur dioxides and gases, a very, very large percent fall into the category of toxic metals.

Kent Ballentine: I have had some familiarity with some of the slaking of the ash, and the runoff from that operation is pretty high in metal, too.

Frank Titus: The ash, per se, is really not so bad, as long as you don't put scrubbers sludge into it. The ash is for the most part a glass material.

Kent Ballentine: What are you recommending now, disposal in special landfills?

Frank Titus: We find it difficult in working from State to State in what we will be permitted to do, or what is really to be expected in the way of solid waste disposal and in the way of protecting solid waste disposals from contaminating ground water. EPA regulations clearly mandate certain requirements for air pollution. They clearly mandate protection of surface water, but they do not clearly mandate protection for ground water. We find that for practical purposes we have to solve many kinds of problems of what to do with the solid waste. The final authority is how we are permitted to construct solid waste disposal.

Kent Ballentine: This particular set of regs defining BAT states that discharges have to meet the raw water standards that the Public Health Service used in their evaluation study of the nation's public water supplies several years back. They're saying that the best practicable treatment would treat water to the extent that it would meet those raw water requirements. That's not Drinking Water Standards per se.

Frank Titus: But does it state that the leachate in ground water per se, that leachate must be –

Kent Ballentine: No, it just says the fluid applied to the land must meet those requirements.

Frank Titus: Suppose we applied the fluid to the land, and EPA approves and the State approves of the solid waste disposal, we can find no clear statement anywhere in the Federal regulations that specifies how we must construct that solid waste disposal, or how we must operate it.

Bill Walker, Illinois State Water Survey, Urbana, Illinois 61801: Somebody should be looking at the total picture. Obviously if we take their standards, it's going to be at the expense of ground water. We have to look even beyond that. At one particular power plant in Ohio, to create this scrubber system is going to increase the cost of electricity by more than 25%, that's one factor. Second, to obtain the lime that they need, this will require that they develop a deep mine. Then this lime will have to be quarried, barged up the Ohio River, unloaded and trucked to this power plant. Apparently, nobody has looked at the total picture. The total fuel that you're burning in trucks and barges. Then of course, the biggest problem is the sludge itself.

Kent Ballentine: We've heard some of the negative aspects of land disposal; what about some of the positive? Certain costs are quite minimal in land disposal–probably more so than other ways of treatment–it could be the most economical way. Are you knocking land disposal, per se, or is it on a site by site, case by case basis? The regs themselves come out and say you still have to consider the most economical treatment system. We're not locked into land disposal, but we have to consider it.

Kenneth Webb: Who thinks land disposal is very site selective? I guess the thing that hurts is the emphasis that was put on land treatment. I don't like the term disposal, but the emphasis was put on land treatment by EPA.

Unknown Speaker: Don't you think, Kent, that it's too late, that maybe it was feasible a hundred years ago when land was sparsely settled? Isn't it Melbourne, Australia, that has this tremendous system that produces and raises cattle, and they probably pay for their own sewage system, I don't know. But, today like so many ideas that were successful 50 or 100 years ago, it's too late because of the population pressures and ideas on values of land and what they want that land to be used for.

Clyde S. Conover, U.S.G.S., 325 John Knox Road, Tallahassee, Florida 32303: What would be accomplished if all the pollutants by man were taken out of the streams–what would be the result on the surface waters? Rivers and streams under natural conditions are nature's sewers. They receive all the by-products of all the chemical and organic actions of nature. This is where all the wastes of nature go, into the streams.

So the alternative to not spending a lot of this money is discharging wastes on the land surface. Now we are upsetting nature's hydrological sewers–I mean the streams are nature's sewers–that's what we need to replace. We're now forcing man with his waste products to put these products on the land which is a source of the fresh waters. I think we're trying to legislate against nature's laws.

Arnold Schiffman: I'd like to have you clarify what products are normally in the stream and I'm wondering in terms of putting man's by-products in the stream, how this is living with nature since to me it looks like it's a short circuit of nature. Primarily, man's waste–we're thinking of residential, not industrial wastes–would be a matter of food products. We generally don't get them out of the stream. We generally get them off of the land and it seems to be a more reasonable approach to put them back on the land and recycle it that way rather than dumping it into the streams.

Clyde Conover: Well, assuming these are beneficial to the land –

Arnold Schiffman: Well, they are certainly not beneficial to the stream.

Clyde Conover: Well, that's nature's sewer. It is there anyway.

Arnold Schiffman: I beg to differ. I don't quite see how you equate the natural streams, lakes and so forth as nature's sewer.

Clyde Conover: Well, they are nature's sewers. There is no question about it. All the erosion from all the lands eventually get into the streams. The excesses either must run off into the stream, be evaporated, or go into the ground water. If the water is not good enough to put into the stream, I don't understand why it's good enough to put into our drinking-water supplies.

Arnold Schiffman: You don't recognize any renovation of waste water by filtering it through the soil –

Clyde Conover: There isn't that much renovation–there is some, but those nitrates . . . you go into an agricultural area where farming leaches the soil, the quality of underground water is deteriorated tremendously. This is natural. This would be a natural process of putting water on the ground. It's just as fallacious to say that water is purified by going through the ground, as it is to say that it's purified by going 50 feet down the stream.

Paul Plummer: Is that true? Are both of those statements true? There is some purification of water by simply putting it into the stream and allowing reoxygenation to take place?

Clyde Conover: There is some purification in the stream. These things are axiomatic. Just because you put it on the ground doesn't mean that it will be purified. There are certain filtrations that have to go on, and some of the nitrates still get into the ground.

Arnold Schiffman: You're going to have that directly in the streams rather than going into the streams indirectly through ground water?

Herbert B. Eagon, Jr., Moody and Associates, Inc., 1631 N.W. Professional Plaza, Columbus, Ohio 43220: It appears to me that what we've got right here is possibly one of the objectives we're getting at. We've demonstrated that the stream has certain qualities or capabilities to purify the water. The ground also has certain capabilities. Now, what we're really pointed towards is finding the cost-benefit and the capacity of each, and using it to the full extent, rather than saying that land disposal is a panacea. Dumping in streams is a panacea. I think it's got to be the proper balance of each, and that's really what we're pointing toward.

Kent Ballentine: Most everybody is making a tacit assumption that if you put it on the ground, it's lost to the stream, and this doesn't jibe with the hydrological cycle. Most of these sites are going to be close to surface water and you're obviously going to get some infiltration.

Unknown Speaker: Do you really see at this time a move toward land treatment?

Kent Ballentine: Well, the way that we interpret the regulations is that it must be considered. There are certain cases, for instance, New York City, where it's just not practical at all. But for certain small communities where perhaps the selection may be between a lagoon or land disposal, then maybe it is a viable alternative. I don't think it's intended for all situations. I guess that Corps report concerning Chicago's waste is due out pretty soon. Anyway, that's what they're talking about, putting water on land in Indiana.

Paul Plummer: Is taking 3 counties in Indiana out of economic production a really viable alternative? I would say no. That's Jasper, Newton and Starr Counties or something like that. Anyway, it's western Indiana.

Unknown Speaker: They might do all right in the sand hills, because in that way it would be "out of sight, out of mind." If they are going to try to apply extensive or concentrated application to something like the Val Pariso—which consists primarily of clay hills, all they're going to get is a lot of runoff.

Kent Ballentine: I don't know what the Corps is recommending, but I know that land disposal is a consideration.

Unknown Speaker: Well, isn't there a lot of safeguards built into your EPA standards to protect against this sort of thing?

Kent Ballentine: Well, yes, as I said, the waste must meet the requirements for raw water that the PHS used for their evaluation studies of domestic treatment plants. The water has to meet these requirements before it is applied to the land surface.

Paul Plummer: If that is the case, there is no land application that is feasible. There is no way that you can apply sewage to the land and have it meet Drinking Water Standards.

Kenneth Webb: Well, I don't think that this rules out land application. But each and every application, or the place that you try to apply this, you've got to be careful how you make use of the hydrology and hydrogeology.

Kent Ballentine: It says in the guidelines that "the criteria for the best practical treatment in a land application system require reducing chemical and organic pollutants to raw or untreated drinking water supply source levels." This requirement would apply to both effluent and sludge. I think they're just talking about applying it. They're not assuming that it's going to be an underdrain system.

Unknown Speaker: What is the criteria, say, for nitrates in the raw water supply, and dissolved salts?

Kent Ballentine: Nitrate nitrogen levels are 10 mg/l. I don't think dissolved salts are in here. They've limited chloride to 250 mg/l, but they don't have TDS, per se. Sodium is 270 mg/l, sulfate is 250 mg/l, but no TDS, per se. I want to reiterate, though, that these are proposed; I don't know what the final regs will look like.

Clinton Hall, EPA, Washington, D.C. 20460: If the water has to meet raw drinking water standards to put it on the ground, what's the purpose of putting it on the ground? Why not just put it right back into the stream?

Kent Ballentine: Of course, this is saying chemical-organic, they are not saying bacterial or viral. EPA has taken the position that they will not go along with direct recycling of waste from the plant to the raw water intake.

Clinton Hall: But it is of comparable quality?

Kent Ballentine: That's what they say.

John W. Bauer, U.S. Army Environmental Hygiene Agency, Aberdeen Proving Grounds, Maryland : I believe that the standards we are talking about do not really apply to the water that you are applying to the land. Let's assume just for a minute, we're talking about ground-water quality. Should they be applied to the water monitoring a certain well, on site, perimeter of the site, or just before you might enter a certain stream? Where do you want to apply standards?

Kent Ballentine: How would you control that? If you don't control it at the point you discharge onto the land, where else are you going to control it?

John Bauer: At the monitoring wells. Assuming that is the way we're going to do it. I'm asking where is the appropriate place to monitor against any given criteria?

Kent Ballentine: According to these regulations, apparently the point they selected is at the discharge plant. *

Rollin W. Harden, Consultant, 3409 Executive Center, Suite 211, Austin, Texas 78731: What about all those places that the naturally produced ground water will not meet the PHS standards? Do we use it and then treat it?

Unknown Speaker: This would be the problem in northwestern Ohio also. At least half, probably more, of the municipal systems up there, have sulfate concentrations that exceed Drinking Water Standards. They are 250 to 500 mg/l, and higher. Many municipalities up there now use this water. If they had to meet zero discharge, they'd have to shut down their water plants because the raw water that they put through their plants can't meet those standards.

The base flow of the streams are the same water. It's not ground-water quality, so the base flow of the stream itself does not even meet those standards. And so how can you apply zero discharge standards where the ambient quality in those streams doesn't meet the requirements?

Duane L. Whiting, Kennecott Copper Corp., 1515 Mineral Square, Salt Lake City, Utah 84111: I believe that the answer to part of that question is to allow a consideration so that you are allowed to discount or subtract the amount of contaminant from the amount that you are discharging. In this way, you are not penalized for the amount of contaminants in the raw water.

Wallace D. Robison, The Anaconda Company, Star Route 1, Box 140, Heber, Utah 84032: Presently, we are operating in Utah where we have natural ground-water flow out of the mine about 8,000 gpm. It doesn't meet class C standards for the State of Utah which means the water can be used for recreational purposes other than swimming, fish raising, livestock raising, pasture. Class C standards are a lot more lax than our Drinking Water Standards. But presently, this water that's going out of the mine would flow even if the mines were shut down. It's been doing this for the past 8 years. It doesn't meet the requirements in terms of sulfates, manganese or iron and yet the EPA classifies this as a discharge, as an industrial discharge, and the route that we're taking with that, and the EPA is working along with us, is a nondegradation policy. In other words, we can't do anything to that water to decrease the present quality. We're not going to be required to clean it up and there's nothing we could do even if we shut it down. With this zero discharge thing coming in, I think that the law is going to have to be more specific to a particular industry. It can't be a blanket thing across the nation. You have to treat industry different than you have to treat municipalities. You have to treat mining different than manufacturing.

Kent Ballentine: I believe the effluent guidelines do that. They go industry by industry to define what BPT is and what BAT is.

Unknown Speaker: The heat standards require that the water temperature not be raised more than, what, 5 degrees, something like this. If this in fact is the case, there are an awful lot of people that would have to put coolers on their effluents because the ground water they're pumping in the winter time is warmer than the water they're pumping in the spring! It just seems like somebody had their head in the sand when they were writing these things.

Harold E. Thomas, Resources Development Associates, P.O. Box 239, Los Altos, California 94022: Are there generally rules for zero discharge? For instance if you have a farm with 9 cows, is that zero discharge?

Kent Ballentine: As I understand it, if a farmer has a certain number of animal units, he would have to have a permit. He'd be classified as a feedlot and he'd have to have a permit for discharge of waste.

Harold Thomas: Even when he's doing this on his own land?

Kent Ballentine: Well, from his own land to navigable water. In other words, the permit program is for discharges to the navigable waters of the country. If they have no discharge, they don't need a permit. There is no permit required right now for that type of thing—at least not that I'm aware of.

Harry LeGrand, U.S.G.S., Box 2857, Raleigh, North Carolina 27602: I can foresee in the future the concept that might be called acceptable or tolerable, which might be adopted as far as the ground environment is concerned. If we could put all of our waste into saturated zones all over the world, I think that would be a nice place to put it. But, of course, we can't do that. Our wastes are concentrated where the people are. So, I think that we are going to have to set aside certain local standards where the wastes are and use some sort of philosophy of tolerance or sanction. This comes back to the idea that perhaps each waste site in the population center is an entity in itself.

E. W. Ramsey, Virginia State Water Control Board, 2111 N. Hamilton St., Richmond, Virginia 23230: One alternative for the future for some wastes—I'm not saying always—would simply be to dedicate a certain area, carefully defined geologically, geographically and engineeringly, which might be defined to receive these wastes at the expense of a hazard to ground water. We have heard quite a bit of comment about the way the legislation presently exists.

Kent Ballentine: What would you recommend changing in the legislation to protect ground water? Would you want to say zero pollutant discharge to the navigable waters or ground waters?

Unknown Speaker: I think that what you have to do is evaluate the resource in the particular area, wherever it happens to be and whatever wastes you have and to deal with these in an intelligent manner, in a total systems analysis. I can envision that you could call it environmental zoning. You can look at it and decide that this area is dedicated to waste disposal. This area over here is going to be dedicated to growing forests, etc.

Richard M. Tinker, General Electric 816 State St., Santa Barbara, California 93013: There have been several comments alluding to a lot of economic factors here. I'm working on a project now with 3 economists working on these questions of the economy involved in monitoring ground-water quality. Questions are being raised here, and it was brought up that AWRA might pass a resolution saying, "Thou shalt not pollute." But, realizing what the costs involved in going from zero discharge approach might be, I think this is a very dangerous approach.

Kent Ballentine: The requirements are for the best available treatment. That's technologically feasible. Now, the goal is still zero pollutant discharge. The legal requirements themselves are still best available technology and I think there is an economic requirement on that goal too.

Unknown Speaker: I think that the big problem here though is that what is a problem in one area may not be anywhere near that in other areas.

Kent Ballentine: What do you mean by " in other areas"—do you mean as between 2 different plants?

Unknown Speaker: Well, yes, 2 different plants perhaps in different locations. One in an arid environment and one in a humid environment. One in an area where evaporation is a very viable method of getting rid of some commodity and in a humid environment where you're not going to evaporate anything.

Kent Ballentine: Well, by definition, then, one would be available to you and one wouldn't. I mean, the effluent standards that are being developed are not coming out and saying, "the best available treatment is this," per se. There are alternatives available. At least that's the way I understand it.

Paul Plummer: Aren't the best available technology guidelines for the industries throughout the United States rather than for various regions?

Kent Ballentine: Yes, but that's not a sole technology, is it?

Unknown Speaker: We talk about the water pollution control act as being zero discharge, and you ask what we can do to prove this thing. Well, what we ought to say is zero discharge, and exclusively say that discharge is for ground water also, or however you want to define that. We say it's zero discharge to the stream, surface water. Let's include zero discharge to ground water. We've got to change the things to where the impact on ground water is recognized.

Paul Plummer: I think the first thing we have to recognize is that zero pollutant discharge can never be a reality in an industrial society. There are still only 3 places to put wastes—in the air, on the land, or in the water—all 3 of these must accept some portion of the wastes. Now, to treat one portion of the environment at the expense of the others, is just ridiculous. Or to treat 2 portions at the expense of the other. Now, somewhere along the line the goal has got to be rephrased. Okay, a minimum impact to the environment—that's a goal. Operate this country so that we have minimum discharge to the surface water, to the ground and to the air. It may mean that there's going to be a lot of money spent to recycle products simply to quit doing things. There are any number of chemicals you can name that have simply stopped being manufactured. We don't make them anymore.

Kent Ballentine: You say minimum. Minimum by what standards? Minimum means something different to each individual. If you're going to minimize waste discharge, how do you quantitate a standard?

Paul Plummer: I don't know. But it seems to me, for example, it takes about 44 tons of coal to treat one million gallons a day of sewage at 85% pollutant removal. And if I remember right, it's going to probably take another 44 tons to get to 97%. We've put the same water in the river, get a little bit of solar energy and a little bit of gravity, and you achieve the same result. That is, no impact on the streams. At least nothing you can measure. We've got to define our priorities.

Gerald Meyer, U.S.G.S., Reston, Virginia 22092: Well, it seems to me that management's toying with this zero discharge mission, and I think anyone of us in the same position would have set the same goal and used the same language and hoped for the best. It's a standard management tool that you shoot higher than one can achieve. To do otherwise admits defeat at the start. It seems to me also that the ground-water industry should adopt the same philosophy, an unrealistic, unattainable goal of zero discharge to the ground-water environment, and enjoy the same benefits that the surface-water system enjoys.

Kent Ballentine: Zero always gives you something you can compare against.

Unknown Speaker: I think Jerry's got a good point. I'd like to distinguish between the goal of zero discharge and the application of technology to the concept of discharge to the surface water and discharge to the air. The important legal factor that distinguishes ground water and concerns the EPA is that the ground-water regime is not being used, in realistic terms, to recognize what the geological restraints are and therefore, I would try to get legislative action or review the definition of the terms to recognize the ground-water quality as it exists, and then allow certain acceptable levels of discharge of pollutants through the ground water just as certain levels of pollution are now being allowed to discharge through the air and streams. Furthermore, we all know that dispersion is an important factor in ground-water quality and that the same factor of dispersion is acceptable in discharging through the surface water.

Jerry O'Brien, Singer-Layne Northern Division, 5520 S. Harding St., Indianapolis, Indiana 46277: Phraseology is the case here tonight. We talk about zero discharge in the streams and zero discharge into the ground water and I'm a little puzzled here about what we mean by zero discharge in the ground water. We certainly don't mean the zero discharge in the ground itself?

Kent Ballentine: Yes, we're talking about general zero pollutant discharge, not zero water discharge.

Jerry O'Brien: The ground water—the ground, it makes a lot of difference.

Unknown Speaker: We're back to the point where I questioned before. Where do we measure the chemical characteristics of the discharge?

Kent Ballentine: As I read the proposed regs, it's at the end of the pipe.

Harry LeGrand: Coming back to my point again, if we say that we can't contaminate the ground water in Akron, to me, that means that we can't drill a well and put waste in it. This doesn't mean that we can't put waste on the ground. I'm afraid that some regulation might be read that might be rephrased.

Kent Ballentine: These regs are talking about land disposal on the surface of the ground.

Glen L. Faulkner, 325 John Knox Road, Suite F241, U.S.G.S., Tallahassee, Florida 32303: We all agree that there should be no discharge directly to ground water. At the same time he's saying let's don't wipe out any legal discharge to the land surface because there is treatment between the land surface and the water tank. Because if you eliminate the discharge to the land surface, then what do you have?

Unknown Speaker: How do you resolve the situation of irrigation? You're discharging perfect quality water and still degrading ground water through concentration of salts and so forth. To me this doesn't fit. I'm not one to stop all the irrigation in the West, because it's a valuable use. But, you've got to take into consideration these uses which tend to degrade ground water.

Gerald Meyer: When you start using technical intelligence and good reasoning in trying to balance allowable pollution of ground water and discharge of pollutants to ground water as compared with zero pollution goals of surface water, then we're adding an intelligence to our discussion that was not present when the zero discharge goal was instituted for surface water. I think we should meet it on the same grounds, and discard all the technical items for protecting ground water. Discard the standards approach which is a hairy one, and simply carry picket signs around petitioning for zero discharge of pollution of the ground water, as a comparable goal, and then get beaten back from that solution.

Kent Ballentine: You assume you're going to lose before you start.

Gerald Meyer: You have everything to gain that way.

Clinton Hall: It seems obvious to me that you cannot legislate an environmental law that will specifically address each individual user situation and define the best solution for that situation. On the other hand, you cannot simply write a law that says that we're evaluating situations eventually and do what is best for God and country because if you do, you have a law that you cannot implement. So you have to do something in between. And this is when you come to standards. I don't care what kind of standards you set, you're always going to have the man from Texas whose native water is of a lower quality than the standards you set. He's not going to be happy. You have to draw a line somewhere and apply the standards as best you can.

Gerald Meyer: Or change the law.

Clinton Hall: What are you going to change it to that's not going to have the same inherent problems?

Unknown Speaker: Well, I think the zero pollution discharge goal is unrealistic and everyone here seems to agree with that, and yet if it is unrealistic, isn't that a goal you can change?

Clinton Hall: What would you put in its place that wouldn't open up more loopholes?

Kent Ballentine: Jerry, do you think we should try to protect all ground waters with the same degree that we're trying to protect all navigable waters?

Unknown Speaker: I don't see that there's any reason for equating the 2 in those terms—because we're doing it for one we should do it for the other. I think we should use the ammunition or the weaknesses of zero discharge to surface water as a tool for accomplishing some reasonable measure of protection to ground water.

Jay Lehr, Executive Director, National Water Well Association, Columbus, Ohio 43215: One of the problems that ground water faces in trying to be protected, that has been an easier road for surface water, is that there are so many vested interests that care about surface water—the fishermen, the voters, the waters users and even the —

Kent Ballentine: They're recognized as public waters.

Jay Lehr: That's right, and there are so many groups that are involved that care. If you do something wrong you are liable to step on a variety of toes. Ground water has very few friends. We've got an absolutely invisible lobby of individual homeowners that have no collective voice. You've got a few cities that have their own thing going and use massive quantities of ground water. You've got small rural areas that don't have much more voice than the vested owners. So we've got a resource that really when stepped on, you can't hear it say "ouch" very loudly. And this is to me tremendous cause for concern. It needs a much greater champion than it has. It's not inconceivable to me that ground water as a viable water supply in the future, could be totally destroyed. This could happen.

Kent Ballentine: Let me amplify one thing you said there. Surface water has been recognized as public. The law does not apply to the private lake on a man's property. Ground water hasn't had that benefit. It's always been looked upon as private property. So, the public has not had the concern for somebody else's private property. If it's ever recognized as a public resource, then you may have a different legal approach.

Harry LeGrand: We talk about the ultimate of zero pollution of streams, but we can never get zero pollution for ground water. It's absolutely impossible to get zero pollution.

Kenneth Webb: You're never going to get zero pollution in the streams either, Harry, you know that.

Harry LeGrand: The only thing you're going to accomplish is the cleaning up of a few pipes that are going out into the streams. When you equate the total pollution load with what you can manage under any law like this, certain things are excluded. There's certainly no control of land runoff from any broad-based agriculture. What are you going to accomplish when you spend a tremendous amount of money? Now, you're putting all this back in the ground. What you need to do is get something that's realistic.

Unknown Speaker: For the record, and for those who might read the transactions of this meeting, I think it is important that we reemphasize and reinforce what Jay Lehr said. If these provisions of this bill set up a situation that sets in motion those conditions that contaminate a large part of the aquifers of our country, I think our children and our grandchildren are going to be pretty sore at us.

Harold Thomas: When you consider the people who are commanded to make zero discharge, you wonder "where are they?" They must be somewhere close to the stream.

Unknown Speaker: I would like to say that certainly our investigations by EPA show that an awfully large part of the pollution in the aquifer comes from what we call non-point sources, correct? And I think this is what Dr. Thomas was referring to.

Kent Ballentine: Of course, there are now control techniques to reduce non-point sources of pollution. You're not going to eliminate them perhaps, but you can reduce them.

David Johe: I think one of the problems is we're all sitting here discussing this and we all agree. But, we're talking to the wrong people. We should go on record as saying, number one, this zero discharge is not impossible, but it's impractical and it's ridiculous. We should go further and say we realize wastes will be discharged, so let's minimize, let's come up with the best solution we can for all 3 regimes, let's come to a happy medium.

Jay Lehr: The purpose of this meeting I think is to talk to each other and come up with a body of knowledge, which is today's thought in ground-water science. Hopefully, what we say here—if we do our job—may be read by someone who isn't here; any ideas as to how to get it read will be appreciated.

Gerald Meyer: This may be off the record. Jay, you mentioned getting the group opinion of ground-water science, but in what way is the collective wisdom of ground-water science so valuable to the question that's posed here? I am not clear on that point at all. What are the qualifications of someone with a ground-water background, whatever it may be, to decide what's good and bad with respect to ground-water pollution? I would like very much to hear a little discussion of that point as to how ground-water people can take such a firm stand on such a complex social and economic issue, and what there is in their job descriptions that makes them so freely make this position their own.

Kent Ballentine: Let me ask Jay a question first—it concerns your observations of the water supply bill. Now there is no reference in that bill that I can find about zero pollution discharge. The standards that are mandated in that bill, are primarily to meet drinking water standards. So, if you discharge pollutants that don't cause the ground water to exceed those standards there's no problem. Is that right?

Jay Lehr: That's right.

Kent Ballentine: Will the water supply bill in effect undercut the goals of P.L. 92-500?

Jay Lehr: Well, if one was to think that P.L. 92-500 addresses itself to all water, sure. I am not aware that P.L. 92-500 figures where we are going to put any of our wastes. I never read, to my way of thinking, that it applied to ground water, but it certainly is not that impractical approach of saying zero discharge. It is, I think, a much more practical approach. It doesn't say that there would be no waste disposal. It just says that it has to be regulated so that it won't destroy potentially potable water.

Kent Ballentine: But the ground-water supply standards, per se, don't mandate that nobody put any pollutants on the ground?

Jay Lehr: Absolutely not.

Unknown Speaker: We should educate people in hydrology, because it's all clear to us that we recognize the relationship between surface water and ground water. When people are educated in hydrology, then decisions can be made as to what's best for the water, what's best for the environment.

Kent Ballentine: Well, the public is welcome to comment on documents like this report on best practicable treatment—it's put out for comment.

Unknown Speaker: I think ground-water scientists play a role in emphasizing the fact that water pollution does exist. One of the reasons why ground water has been left out of a lot of legislation is the fact that so many people don't really understand or believe that ground water can even be polluted. I'd like to see more agencies at least bringing these problems to the public's attention.

Kent Ballentine: I believe that some of the Section 208 areawide studies will address ground water now. It's up to the planning agency to make certain that it's done.

G. F. Hendricks, Sieio Inc. Consulting Engineers, 309 Washington St., Columbus, Indiana 47201: The ground-water people have a responsibility to talk about these things and make sure that the public or John Q. Congressman knows the difference between surface water and ground water.

Kent Ballentine: The Drinking Water Standards are not cast in concrete; they change periodically, as new evidence comes in. If the allowable concentration is suddenly changed, how do you handle something like that?

Jay Lehr: Practically speaking, the standards don't change. They haven't changed since—what's the last standard, '65?

Kent Ballentine: Well, there are interim standards that are out. But what I'm saying is that, for instance, if new evidence is found, and arsenic or something may have its allowable concentration changed.

Jay Lehr: Sure, it means adjusting practices that may have been going on that weren't considered to be polluting; all of a sudden they're polluting. They're shut down.

Kent Ballentine: But I'm saying, should you just meet drinking water standards, or do you want to say, we only want to have 50% of the allowable value? Do you want to put a factor of safety in there just in case something changes?

Jay Lehr: Well, I think that's an alternate possibility. I just thought of 2 words that might answer Jerry's argument, why the ground-water community, ground-water scientists think they should be ruling the roost in this particular area in determining how ground water should be managed. The 2 words would be, "by default," because nobody else has ever attempted to.

John Wilson, MIT, Cambridge, Massachusetts 02142: I'd like to comment on what Jay was saying relative to Drinking Water Standards for ground-water supplies. My comment is that this seems to be doing exactly what was done relative to surface water some years ago. We used stream standards, perhaps one day when we're economically in control, we will find that zero discharge can be a practical means. Shouldn't we now attack ground-water supplies from these more advanced stages rather than going exactly the same course as was taken earlier for surface water? We could have a systematic assessment of ground-water supplies which we could use—rather than using a set standard—in this case Drinking Water Standards.

Unknown Speaker: Why are we trying to protect surface water? All I read in here is "propagation of fish, shellfish and wildlife." I don't know where health comes into it.

Unknown Speaker: I go back to a classic. There is a classic that everybody should read, a book called the "Conversation of Ground Water," published by Resources for the Future in 1947. Is that the right author? It's not at all out of date. One of the examples is a very exciting one. That is, it relates some of the technical and economic aspects of saline water contamination of the Baltimore industrial area, and the surrounding areas. But, if one were to take the kind of stringent controls that we envision here for ground water and apply them back at the turn of the century in the Baltimore industrial area, there would perhaps be no more Baltimore industrial area and Bethlehem Steel stock would be on the way down. Thousands upon thousands of families would have had to live elsewhere. So there are a tremendous number of benefits that have accrued to this country from the Bethlehem Steel plant and the entire Sparrows Point complex that would have been perhaps stopped or certainly greatly slowed if we'd been concerned about the contamination of ground water.

Arnold Schiffman: I'm from Maryland and the salt water was really not that great. Some of it was defined as 15 mg/l. For another thing there was another alternative. They were pumping during World War II. A choice could have been made and wasn't because, let's don't forget, no one knew about the problem of salt-water intrusion. They took an easy way out.

Unknown Speaker: Could you clarify a point for me? I worked in the Baltimore industrial area. We were called into the area in 1941 or so because there was a very serious ground-water contamination problem. So, I don't know what your point is.

Arnold Schiffman: What I'm saying was that with sufficient knowledge, there was an alternative to it. They didn't have to cause intrusion. They could have pulled from deeper strata.

Unknown Speaker: Well, one of the problems was corrosion of well casings—contamination of the fresh-water aquifer. The whole system was involved.

Arnold Schiffman: I agree that had the ground-water resources not been developed, we wouldn't have had the industrial wastes. I got the impression that you said just go ahead and contaminate it without thinking about it.

Unknown Speaker: No, what I'm saying is that once they realized that it was contaminated that it did not deter them. They continued with their pumping when some alternate sources were available to them. Without that long-range thinking, I don't think the Bethlehem Steel plant would be where it is today.

Jay Lehr: I'd like to try one more answer at Jerry about what makes ground-water scientists think they're capable of answering these things. I think with proper education and this kind of discussion, we can bring ground-water scientists to the understanding that we don't need zero discharge, or we can have zero discharge, then go a step further and actually do some purposeful, I won't call it polluting, let's say storage of wastes. It doesn't necessarily have to be detrimental, but I strongly feel that ground-water scientists have to be in charge because first of all as a body of scientists they're as intelligent as any other discipline—probably too softly spoken, but just as intelligent. Obviously we need interdisciplinary work. We need input from a lot of organizations. But I don't think that there's any other particular group that has any better right to, let's say, lead in the making of these decisions as to how we're going to use and abuse our ground-water resources.

Ultimately, it's the thorough understanding of the ground-water environment that I think will dictate more of the decisions than, let's say, any unique economic factors. I think we have probably a better knowledge of other people's fields than they do of ours.

Kent Ballentine: I'm just curious as to how many ground-water people have commented on these regulations, even though they don't directly apply to ground water. I bet there's very, very few.

Unknown Speaker: On the same line, you point up what a small part anybody in the ground-water discipline had to do with the drafting of P.L. 92-500. Ground water was put in very obviously by interlineation. There is no ground-water language in this thing at all. It's an insert throughout and no ground-water man was allowed in that drafting.

Kent Ballentine: EPA makes comments to the committee on the various drafts.

Unknown Speaker: But the language of that law doesn't include any ground-water terms, no treatment with respect to knowledge or input to ground water at all.

Kent Ballentine: If you read the committee's report, ground water was a deliberate omission. The Senate committee comes right out and says that. Their reasoning is rather obscure, but they say they deliberately omitted ground water because it was so complex.

Unknown Speaker: Well, we agree with them that it's complex, but if they're going to write acts that affect us, then that's a premature act which puts us in a spot.

Kent Ballentine: Well, this is one reason why Jay is working so hard on the drinking water bill because this gives you an opportunity to get some input.

Jay Lehr: In 1864, the judge said it was a mysterious cult, and in 1972 the Senate said it was too complex. Nobody understood.

Arnold Schiffman: What do you think of a plan to tie together surface-water permits with "ground-water discharge permits." You hit them with the surface water, and you hit them with the ground water. Not on a different level, but on the same level as the surface water.

Unknown Speaker: As a scientist, it's rather arbitrary for you to package in one bill that's concerned with abatement or prevention of pollution or whatever, because that's only one side of the coin. The other side of the coin is the need to dispose of wastes. So to be an objective scientist, it's rather arbitrary for you to take a strong adamant position on one side of it, without taking a look at the other side.

Unknown Speaker: We've heard a lot about the deficiencies of P.L. 92-500. And I think we all agree that there are a lot of deficiencies, but I don't think we've heard very much about what you need to replace those deficiencies. This would be a proper area for NWWA to get involved in.

Jay Lehr: We've talked to many senators and congressmen about drafting a companion bill, so to speak, or a ground-water bill. There's a growing interest, but it's got a long way to go. Our initial feeling was that we need a broad ground-water law, but a lot of people I've talked to in the last week have made me recognize the alternate possibility that we can also look at having no federal law as being a blessing and that we might have time to go one by one to the States. We might improve things by going to councils, State governments; working out a State law that would not have the automatic drawbacks that a federal law has with the czar that is always an agency in the federal bureaucracy. We've already got a project, a State law, that might bring something like this to fruition in a couple of years.

Kent Ballentine: Well, I think as a final summary statement, we can say that zero pollutant discharge is still an unresolved issue. There is some question of whether it's technologically feasible or whether it's even desirable. I think each person here owes it to his profession and to himself that when the various regulatory agencies such as EPA, the State EPA's and other agencies, come out with these kind of regulations, that you comment on them. Those of us who work at agencies well know, if you don't get the comments in, you don't get the attention. You may not think it helps but it really does.

Jay Lehr: The most important thing that might come out of this meeting tomorrow is that people who came here go away feeling that they are really a part of something that they never felt a part of before. To be very honest, the National Water Well Association Technical Division exists by and large as a group of subscribers to the Journal of *Ground Water*, and they have never been to meetings as a group before and never really been involved as a part of any national organization working with any single-minded goal. We might achieve a beginning to that. If we do, we'll begin to feel more guilty when part of that group don't read and comment on standards like this. Maybe there will not be another P.L. 92-500 come by without massive comments by our segment of scientific endeavor on legislation like that. Because we've been so splintered and had no feeling of being a part of something like that, we've been able to be totally divided and completely conquered by other interests.

Kent Ballentine: As one example right now, the Section 106 regs on monitoring are out for public comment and there's a section in there on ground-water monitoring including what EPA is going to require. I don't know if anybody here has seen them or read them, but I would advise you to. I'm not sure of the date they were published in the *Federal Register*, but they're out.

Horace Sutcliffe, Jr., U.S.G.S., 232 Rawls Ave., Sarasota, Florida 33574: How many of you gentlemen sitting here tonight in the last 30 days have spoken to a Lion's Club or a Rotary Club? Anybody? Two, three. I'll put my hand up–5. We're talking now about regulations of an industry and dissemination of information from a body of scientists through a political body which consists of shoe salesmen, real estate, a few lawyers, and these are the people that control our dollars at home, in your hometown or wherever you work.

They know absolutely nothing about ground water 99% of the time, but all of them belong to some civic organization, including economists and senators. Believe me if you want something to happen, this is the place to start it. Now, Jay has started this with the drillers; formed a speaker's bureau at least in Florida which is active. This is one of our answers to education, but it takes individual efforts.

Jay Lehr: We have an editorial in the October issue of the *Water Well Journal* about how easy it is to get on a civic association program and give them a few minutes of very basic education and open their eyes and get them involved. In the legislative area, the Association has to take a more active role in prodding members to read and comment on these things. I don't think we've done it before. Maybe more people will look up and listen. I think Jerry Meyer has a point about who gave us the right to do it. I think we really do have a right. We've absolutely got to do it and obviously nobody is going to do it for us. I think that general public education is critically important in the next couple of years. One point that's brought up tomorrow will be to change the name of the National Water Well Association to the National Ground Water Association.

Kent Ballentine: Is that one word or two?

Jay Lehr: It's definitely two!

Kent Ballentine: On that little argument, I think we'll stand adjourned.

* **Editor's Note:** *Mr. Ballentine cites his error here. The point for application of the drinking-water source criteria at a land disposal site is where the effluent enters the saturated zone.*

Bull Session — Lesser Known Ground-Water Pollution Hazards

Session Moderator: Robert C. Minning, President, Keck Consulting Services, 4903 Dawn Avenue, East Lansing, Michigan 48823.

Robert Minning, Moderator: The Bull Session this evening is Lesser Known Ground-Water Pollution Hazards and the connotation of that I'm sure is open to as many opinions as there are people in this room. And so this evening if we can, let's just try and exchange some thoughts, ideas, what have you, on some of your ideas about what lesser known ground-water pollution hazards may be.

And to start it off, I'd like to throw one out for discussion. It's a personal matter that we have been involved in, in that a municipality has put in some municipal wells and furnished water supply, non-municipal water supply, to a local system. Previous to that, there was no system, but all the residents' needs at that time had been furnished by private wells. There is no provision, at present, for the maintenance or abandonment of the private wells for all these homeowners, and we're talking in the order of about 3,000 wells, which penetrate and draw water from the same aquifer as the municipal system. Although it's a widely-known pollution hazard, I'm not really sure how you go about handling it or if these things have been taken into consideration in any other area of the country. If statutes are written, should this be part of the ordinance?

Joseph W. Miller, Jr., New Jersey Bureau of Geology and Topography, 4151 Princeton Pike, Princeton, New Jersey 08540: About a 2-square mile area in a coastal plain, I can't go any further on that, was contaminated by chemical pollution. The town fathers passed an ordinance, that all wells of the affected area had to be abandoned. They are putting in city water for the people.

Robert Minning: But this was an ordinance that was passed by the people?

Joseph W. Miller, Jr.: Yes, last week.

Thomas Ahrens, 240 Jersey Street, Denver, Colorado 80220: There is another way they handled it in California, across the bay from San Francisco—they put in an improvement system. Then they proceeded to require all existing wells to have a permit and since they would not give any permits, they sealed them. A friend of mine up there had a well out in the back yard and it was sealed; they couldn't use it.

Robert Minning: Who paid for that?

Thomas Ahrens: The State paid for it.

Robert Minning: The State paid for the sealing and abandonment of all wells?

Thomas Ahrens: No, they did not seal them or anything, they just could not use them.

Unidentified Questioner from the Floor: What is the reason for abandonment of these, if they had to break up cross connections so that they could use these wells to water grass or something like this? Or are you just trying to seal up the abandoned wells with pumps (inaudible) or do you want to fix it so they cannot even use the ones that have pumps on them?

Robert Minning: No, I feel that all the wells will be abandoned simply because the lowering of the water table in the area will force the abandonment eventually of all the wells. Yet there is no provision to have these things sealed, plugged, or what have you.

Thomas Ahrens: But on the other hand, I would agree with Bill, I do not see why they should; after all, that is personal property and I do not see why that law—what they did in California— is constitutional, unless they --

From the Floor: I would say, the thing is, ground water is public property, not private property in California.

Thomas Ahrens: Yes, but a well is private property.

From the Floor: But you are using a public resource. And they can control you in the use of that resource.

Thomas Ahrens: Not without just compensation.

From the Floor: Is this a law?

Thomas Ahrens: I am not sure what the law is, I was just there. I saw their well and asked them if they were using it and they told me what had happened. They said all the wells in that area had been sealed and there are no private wells and they all had to go into the public system.

Robert Minning: Have you had any experience, Wayne, on this?

Wayne Pettyjohn, Ohio State University, Department of Geology and Mineralogy, Columbus, Ohio 43210: Well, in a part of Columbus now, they are putting in some water lines. Of course, a lot of people had wells and septic tanks before and the people can still use those wells for watering the yard. If I had one I would certainly do that instead of paying for city water, because you are paying a sewer charge for filling swimming pools, and so on, and as long as the wells are maintained, and water cannot be withdrawn from them, I do not see why they could not be used. I would be very much opposed to a blanket plating of wells just because there is a public water system.

Robert Minning: Is there a cross connection stipulation?

From the Floor: That is the thing they have to worry about because if there is a cross connection, then the Health Department can close them down in almost every State, I think you will find, and so there is danger that if people have their own well, a lot of times they will just stick a valve on it so that they can go on and use their own water. So there should be some law on that.

Thomas Ahrens: I know they do have a law or two in New Mexico.

Joseph Miller: In New Jersey, you cannot have cross connections.

Thomas Ahrens: They have a law in New Mexico, where if the well is leaking or is not properly sealed, they are told to repair it. If they do not, the State comes in and does it and that goes on their tax bill and has the same status, you might say, as a land tax. In other words, if they do not pay it, they can sell the property and collect the money that way.

From the Floor: Tom, can they do this on oil wells too, in that State?

Thomas Ahrens: It does not apply to oil wells.

From the Floor: Isn't that cute?

Thomas Ahrens: Yes.

Robert Minning: Only to water wells?

Thomas Ahrens: Just to water wells.

Robert Minning: This is a local ordinance or a State statute?

Thomas Ahrens: State statute. And the State Engineer administers it.

Robert Minning: Does anyone else have any experience? Greg, have you had any in Ohio?

Greg Stockert, Stockert Drilling Co., Inc., 1372 N. Wooster Ave., Strasburg, Ohio 44680: As far as the mass plugging of wells in an area, not as yet. The Health Board is taking a look (inaudible) and they are constantly checking on it but as far as mass (inaudible).

Dale Vern: There are several of the States in the

West, of course, that have this kind of a law. Hawaii, for instance, is one of the leaders in this sort of thing, particularly in their artesian zones on Oahu, where they have a very tight control. Any well that is taken out of use at any time must be either sealed or re-equipped according to specific instructions from the State Engineer. I think even in the New Mexico case, the oil wells are subject to the same law, within that zone of fresh water. This is pretty general in most of the States, at least that I am aware of.

Robert Minning: We don't have to stay on this particular item—the idea of the session is to let anybody talk about anything they want to. If you have something to say or have a question you would like to ask, let's just keep it open and informal.

William H. Walker, Illinois State Water Survey, Urbana, Illinois 61801: I notice that we are going more toward hazardous spill concern in this country, with laws and things. It seems to me this might fit into this unusual category because they are hauling everything over the roads and railroads in this country. We had 2 hazardous spills recently in Illinois, for example. One was 25,000 gallons of cyanide that was dumped out into a corn field in a railroad accident. They contained this within a levee, half-moon-wise, around the railroad. That was in November 1969. They are still working to clear it up. They have spent well over a million and a half dollars on it so far. They thought they could put HTH on top of the ground and let this take care of it; however, they found cyanide is down in this clay on top of the water-bearing formation and they are having to dig up this clay and pulverize it to get the HTH to work with the cyanide type of stuff. So some of the spills like this are very long-lasting and can be potentially hazardous from a ground-water standpoint. Another thing too, had this wreck occurred just a quarter mile down the track, it would have fallen into a stream that fed the lake that feeds this town, so it seems to me that even though this is not the kind of thing maybe we are concerned with, it is in one sense, in that it affects ground water indirectly, or could conceivably do so. In the other sense, I think we ought to look at hazardous chemical hauling over the roads, from our profession, with a little bit more concern than we have in the past. And along that line, I would like to see somebody submit some good laws on this, with our input into it, because everybody is passing laws right now, without input.

Jim Howard, Moody and Associates, Inc., R.D. 4, Cotton Road, Meadville, Pennsylvania 16335: We have spent a great deal of time on the legal aspects—perhaps we should get back to the lighter things. It is a very worthwhile continuing endeavor, and I am not sure what the other peoples' experience has been, but as far as actually handling those accidents that occur, we are doing very little about dispensing technology and procedures on how to do it. We have been working in our company with hydrocarbons and with hazardous materials for a couple of years now, and during that time, I have bounced off EPA and several other organizations that did not want to hear about it. The first paper I have heard yet that dealt even in a general sense, with some of the mechanisms—although there are a few papers—API has one out—the first paper I have heard about hydrogeology concerning potential mechanisms and geologic interaction adequate to analyze movement, other than leaching, was today. Now there are a lot of other things for example, ethylene glycol, which are heavier than water, and interesting to handle. In a stream, it drops down through it nicely, having high specific gravity. It is heavier than water, it has a high specific gravity, it has completely different requirements for handling. Yet, we are not even working among ourselves or concentrating on letting each other know what techniques and procedures may work. So we are talking about laws when we are not even attacking the situations that exist. Now again today, I think Osgood said that since 1971, we have had 300 reported occurrences in Pennsylvania. In other States, I know, that are near Pennsylvania, there are a number of the American Petroleum Institute people who are attempting to handle this problem without high public relations emphasis. This is admirable, no problem with that. You fight for yourself and these guys, the ones I know, are qualified to tackle it. But, in one State I know, the State has heard of 12 spills approximately in a year. The man who handles it for API receives nearly 45 a month and on that basis, I would feel that very probably even the ones that are really serious could be up to 100 a year. Three hundred reports in Pennsylvania sounds like a rather large sum; however, 45 times 12 is a little larger. At any rate, the mere fact is that we are not communicating or emphasizing among ourselves the context of how do you tackle this thing. I have mentioned too, only one thing—hydrocarbons—there are 5,000 of these things coming out, sooner or later from the EPA. Somehow we have got to get together on our own.

William Walker: Over in Britain, Harwell, which is the Atomic Energy Commission sort of thing over there, they have an emergency hook-up such that people all over the British Isles are on duty 24 hours a day in case of a spill. They have the labels so that they can go out and, for example, if a policeman sees a truck overturned, there is labeling on it so that he can call in immediately on this red telephone. They have a helicopter rigged with all sorts of emergency gear and testing equipment and everything else. They can fly to the site. They have a trailer rigged up so that they do this same sort of thing. These people are schooled in how to do this, and they must notify these people. This started because a woman came upon a wreck a few months ago over there and she did not know what it was; she saw the driver was in trouble and got out of her car and walked across the road. The wreck was some vile acid and there was a pond of it there by this time, the acid fumes overcame her, she fell into the acid and was practically consumed. After that, well, they got more concerned about this type of thing. So here are the kinds of things being hauled over the road, and there is no way of standardizing all of Europe. I tried to check on this, they have a different system all over, but there should be a way of looking at a truck that is turned over; for instance, just have one simple numbering system and a color code maybe, so that the police can say I've got a red 5 and they know that a red 5 is something. And then he can read a number off of that truck that is on a computer, for instance, and then call a red 5 number truck at the end and any truck that is shipped has to be listed for that day on what it was carrying. That way, then, he would know to evacuate the area or whatever. One fellow told me that gasoline by itself, if you have a wreck, is not too harmful, but it makes a pretty good boom. Then he named something else, and I do not know the chemical, he says that one makes a pretty good boom, but, he says, with all of these trucks on the road carrying both of those things, sometime, somewhere in the world, something is going to happen and they are going to come together. He says, if those two ever come together, it is going to look almost like a hydrogen bomb blast, because it would pulverize everything for a half-mile to a mile around. This is the kind of thing, it seems to me, that if each one of these people are trying to take care of their own, I think it is a bigger job than that. I think we owe more to this thing than to say that they are doing a good job. I think something should be done tomorrow so that they —

Jim Howard: I might not rebut but add a little bit to that. I think my point is the fact that we need to keep control over attacks on legislation. No matter what laws are passed, we cannot abolish carelessness or accidents 100 percent and until we ourselves have developed the technology and approaches, to make sure that as technologists, consultants, company people, whoever we are, we are able to go out and handle those emergency situations, you are going to continue to have the things happen like block-long elements of New York City blow up, which happens fairly regularly, according to a buddy of mine in New York City. Or you are going to have the communications system for Indianapolis and the Army payroll center wiped out because of gasoline contamination that eats through all insulation and their materials. But the problem is to know how to tackle those things. There is one job where they pulled in an electrical engineering firm to handle the recovery of the hydrocarbons. So they are now becoming experts at hydrocarbon recovery on Bell System money. We are not even saying we can do it, but those of us who have had a little experience, pooling with the others who have had it, can make the job a lot more effective.

Robert Minning: One problem from a private consultant's viewpoint, you get a client who hires you, sometimes you are hired with the understanding that the State agencies or Federal agencies do not know a thing about the problem yet. And written in your contract is that you will not divulge any information on the project until authorized to do so. How do you go about exchanging technology on this basis, and a second thought is—even when you do develop that, it does take your time and your effort to write that up and to contact other people in our profession about that. And how do you justify that?

Jim Howard: May I answer that as another private consultant? You may not, under the rules and ethics of a consultant operation, divulge invormation concerning a project in which you are involved. You may, after 5 or 6 or 10 or 12 of these jobs, put together manuals and discussions of the procedures for handling this type of situation. You may ask the company for release of information, or you may, if you are in Pennsylvania, for example, and are required to submit full reports to the State because they require the man who hired you to do so, assume that is not privileged information. Now, as to how and why you put it out, if I may be relatively blunt, you, Dick, the other people here and I are here for a number of reasons. One, because we wanted to contribute to the profession. There is a second reason, the practical reason, in that there are clientele with which we may eventually work scattered throughout the people here. There are also competitors. Now in terms of providing model situations, as I see it, the expertise which I can bring to bear, or my people can bring to bear on a given situation, is not going to be answered by a model situation. Model situations will give an approach. It must be modified in view of my own experience and my own knowledge as a consultant. Therefore, by giving a model, I am not telling someone how to do it, I am telling them that it can be done and that there are methods and technology to handle it or that there are not methods and technology to handle it because we blew it, or the USGS blew it, or the EPA blew it, or Illinois blew it. Again, I am speaking as a personal opinion, but unless we do begin to let both ourselves and other people know that they can be handled, that there are ways of attacking it, or identify those that we do not know yet how to attack and learn how to, then, all the legislation in the world isn't going to help that much, because even if legislation exists it is going to be considered that there is no way to solve the problem.

Bob Scott, U.S. EPA, 100 California Street, San Francisco, California 94111: Do you have a case history in mind?

Jim Howard: Well, I can take a generalization, perhaps, although I am not sure that it is completely valid. I'll take the EPA opinion towards ground water and hydrocarbon contamination. As of the conference in Washington a year and a half ago, when I went to a 4-day meeting on oil spills and hazardous materials and handling, in which one paper from Mississippi, as a side issue, mentioned the fact that some of the spills had gotten into a gravel deposit. For the purpose of determining federal market for my company, in terms of handling hydrocarbons in which 5 projects were underway with oil companies at that time, I approached about 4 officials that I feel were reasonably well up in the areas of EPA, and was told effectively that they had no authority and were not really able to talk about it. And at the San Francisco meeting, dealing with the same subject, I know at least 2 papers were submitted dealing with ground-water contamination with hydrocarbons, but were not accepted because they were not relevant. That would suggest that the past 2 years have not made that much change. This means that they cannot do anything about it, under the law; therefore it is of no interest. In my opinion, presenting papers at a meeting has no reflection on whether or not there is a legal authority to handle it. That is not to say that information should not be disseminated for States, for example, who do have laws requiring procedures. Again, I am speaking as an individual.

William Walker: There is a grey area. The State of Nevada has a hydrocarbon pollution of a ground-water factor right now. It has been going on since 1971. They have been unable to abate or even decide the specific cause. They have come to EPA for assistance and through our technical assistance responsibilities, I am helping them on with this. In no other way could I get involved with it. In other words, the States are responsible for ground-water pollution.

From the Floor: I agree, I am not (inaudible) the EPA. Are you saying they should assume the responsibility?

William Walker: No way. They do the laws just like everybody else.

Jim Howard: Right. The feeling that, since there was no authority, that even permitting or having a non-relevant paper dealing with the problem itself in handling it, within a general symposium, strikes me as carrying that interpretation of the law a little too far.

Bob Scott: I did not go to the symposium.

Jim Howard: It was not my paper that was submitted. I was going to and for other reasons –

From the Floor: Whose symposium was it?

Jim Howard: EPA, API, and the Coast Guard, as I recall.

Bob Scott: It was surface-water oriented.

Jim Howard: I think the title was "Oil Spills and

Hazardous Materials Handling." The last one was held in Washington about a year and a half ago.

Bob Scott: I am the region 9 hydrologist and I was not even invited.

From the Floor: The problem is that the environment people are concerned is not my problem (inaudible) at the symposium. It is difficult to get authorization to present a paper that had cleared (inaudible). It is not that we are not concerned ourselves but a lot of times it is difficult to get clearance—the kind we need, even though we have data which is pertinent both to government, State and utilities.

Jim Howard: I would not argue with that. He asked for a case example, I presented one, and that I think has reinforced my feeling that in NWWA, if we feel a gap exists, we should make efforts within our own organization to fill those gaps we can identify—because of red tape or other problems—I am not arguing that these problems exist, I was only using it to point out the gaps which must be filled and no one else is filling them.

From the Floor: Are you familiar with part C of the House bill, I think it's HR 13002. That indicates a gap exists—if that bill does not pass, perhaps NWWA should move into the vacuum.

Jim Howard: I would suggest that if it passed or not, in terms of translation of technology, NWWA should move in anyway to supplement the bill.

From the Floor: I was wondering—Jay Lehr mentioned in the keynote address about the bill pending—why there was not a telegram or such sent from this organization to this meeting in Washington. I sort of expected something.

Jim Howard: Very simple, there are a number of reasons. Number one, not everyone agrees with every facet or portion of the bill which is visible. There are facets of the bill which may, depending upon the interpretation of the EPA, provide a hardship for the drillers, a hardship in terms of income. As a whole, the NWWA, as I understand it, is behind this bill. There are provisions of portions of the bill with which many do not concur and I do not know what the policy is on organizational factors. Jay Lehr is serving as a spokesman for NWWA for that bill. Now I am not too sure that a telegram would be much more effective than testimony before Congressional committees who are responsible for passage of that bill.

Robert Minning: Let me ask a question here—the discussion was brought up revolving around hydrocarbons, that Jim brought up. How many people here have had any experience in hydrocarbon contamination of ground-water aquifers? Can we get a discussion going on this? What happened? What occurred? Why? And how were they solved?

William Walker: I would like to charge this discussion, though, with the fact that why worry about little silly things like hydrocarbons that every one of us can be experts on by smelling or tasting, unless we want to put chlorinated hydrocarbons in front of us. Why are we arguing about these little salts and chlorides and nitrates and hydrocarbons—you know, sure there are a lot of them and they are irritating and all that—but are they all that important when you get down to it? Everyone that I have ever seen has been in contact with one isolated well or series of wells that have been affected, but I think we could cop out on that one too. I should not have said that maybe, but I would like to have that addendum studied.

Thomas Ahrens: We had a town that was sitting on top of a million plus gallons of high octane gasoline, rising and falling with the tide. One house caught fire (inaudible). They never found out whose gas it was, but there is one woman in that town, the man tells me, that had a pitcher pump. When she wanted to run her lawnmower, she would go out and pump. One of the (inaudible) took on the job of removing the gasoline for the industry and is now down (inaudible) one-half an inch of water, gasoline, on top of the water. They did this by pumping and they are just finishing up after 2 years.

William Walker: There are several gas industries in this area or just one?

Thomas Ahrens: There are 5 pipelines, and 4 large oil companies, one major and the major company, and I cannot say the name did all of the work and they were reimbursed by the other oil companies. But this was really a major spill.

California: You say they did not know whose gas it was. But they had to find out where it was coming from.

Thomas Ahrens: They know *where* it was. The

State Bureau of Geology went out and with the head geologist of the oil company, we set out a pattern and put down observation wells so we could delineate the area and get cracking on the pumping job. That would pinpoint the general area which it came from, right in the middle of the 5 pipelines and right behind them were 3 rings where great big oil tanks or gasoline tanks had been removed in the last 5 years. But the companies said they were not leaking.

California: Mr. Walker doesn't seem to think that oil, or nitrates or sulfates or chlorides, or anything along this line are worthy of study. What are worthy of study?

William Walker: Basically, I think we ought to set priorities putting the most hazardous at the top of the list and spend more money and effort and time on those and spend a minimum of time on these others. Now granted, you have to work a little bit in chlorides and nitrates and things to perfect technology but once you get it done, and here I have asked a question, how much of this do we have to do before we prove to everybody that that is a viable method. But let us accept some of these as viable methods we know would work, that we have proved on these cheap ones, and then get into some of these, because if we can divert some of these 400 people in here into working on the real hazardous ones and solve them first, then these others will kind of take care of themselves, and even if they did not they would not kill anybody.

From the Floor: Aren't they localized problems just as well as the nitrate?

William Walker: They might well be but a localized problem, such as phenols is much more serious a problem than a localized problem of nitrate. Because I have pictured little girls, born and bred, and raised and everything else on 500 ppm nitrate. Now, sure, maybe she did not have some brothers and sisters because of this, but what I am saying is that one at least made it. I do not think you would have that much with 500 parts of phenols.

From the Floor: Mr. Walker, the most hazardous material is radioactive, do you want to get into that?

William Walker: I think someone should, but I don't. I tell you, I would not know how to sample that stuff, quite frankly and it frightens me to death, I am going to have to pass on it.

From the Floor: You sample it like you do the chloride.

William Walker: Yes, you might lose a family there. No but seriously, this kind of thing is hazardous. In Illinois, for instance, they are dumping one curie per cubic foot type of stuff and calling it low level. Over in Germany, they took one look at that and were horrified, and they said that is high level. So you see, what are we calling this, high level and low level –

From the Floor: How many people are involved?

William Walker: There are not many people around there to speak of, thank goodness, but, I mean, how many people were involved over some of these others. It seems to me that –

From the Floor: Now in the United States today, there are about a million people drinking ground water from public infested water supplies that exceed KHS standards of radium. This is natural, this is not man pollution.

William Walker: That is like my Epsom Salts thing I read today. We try to blame God for all these things, but man added part is what I was trying to infer there. Man is causing some addition, we can't do anything about God's part, but man surely we can control. That is the point that I was trying to make awhile ago. Or we can quit dumping that stuff out there on the ground.

From the Floor: That area I spoke of earlier was 2 square miles. An unscrupulous trucker dumped about 6,000 fifty-five gallon drums of solvents of all types in sand, with no clay barrier above the ground water, and the problem is now to put activated charcoal in to make the water palatable. But what did the solvents carry along with them? And if you pump it out, you can't put it in the bank. What do you do with it?

Robert Minning: I would like to interject here on some of the comments passed over earlier, and I guess it goes about how you define hazardous and I get the 2 different impressions from the comments that have been passed around here, one of the attitudes seems to be that the degree of severity of the material that is spilled constitutes the hazard and the other is the amount, and the frequency of a certain type of spill, constitutes a degree of hazardousness. First thing, I do not think you can neglect either and when you start setting up priorities and say that we are only going to study this because we already know how to solve hydrocarbons, does not negate the fact that the amount of damage caused by hydrocarbon spills may in fact be much more, I don't know what the order would be and I have no idea, but I will say for example, 5 to 1, hydrocarbon spills versus toxic chemical spills. Now, how do you resolve that? Do you just say that we are going to forget about the hydrocarbons?

William Walker: Well, I think, when you say there is much more damage done, it is so nebulous, Bob, in that we do not even know the subclinical effect of some of these hazards. That arsenic case I pointed out in "Where Have All the Toxic Chemicals Gone?" the doctors treated those people for 3 weeks for something else before they happened to even think about arsenic, and then they started looking for where the arsenic came from. This thing is happening all over the world and so when you say then, the effects, we do not know. Some of these people who are dying early could be from these other things, I am not fooling around now. I am just saying we do not know and the doctors do not know a typhoid fever case before, they have never seen one. They tell me that in hospitals when a typhoid fever case comes along, the doctors come from everywhere to see it, just to see what typhoid fever looks like. So if we do not know the tolerance level of some of these hazardous chemicals and do not know how to recognize them when they come along, how can we say that more people are being affected by hydrocarbons than we can some of these others?

From the Floor: You talk about chronic effects, though, along with the things you would like to dismiss are in that level of possibly related to chronic effects. I mean, nitrates in Norway have been banned because of the potential carcinogenic relationship. Papers have recently come out from the British Bureau of Cancer showing high nitrate waters relating to the increase in stomach cancer. (Inaudible) down in Texas shows that the High Plains runs 30% to 50% lower stomach cancer than, say, central Texas. A reasonable mechanism for that can be nitrate.

Roy Spalding, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska 68428: I would like to interject a couple of thoughts. First of all, the hydrocarbons may also be the solvent by which you carry things like ECB and EET in the ground water, so the 2 are pretty well intertwined. Secondly, in Nebraska, we have one place where we have 50 miles of nitrate, high nitrate salts—of that 25 miles of it is averaging above 15 tpm nitrate nitrogen. Some wells, the highest one is about 400, and in zones where you have got 20 tpm nitrate nitrogen—well, in these zones of high nitrogen, farmers are reporting that their pigs suffer from vitamin A deficiencies. It has been fairly well documented that there is nitrate toxicity in the vitamin A formation in the liver and there also has been some reports of (inaudible) in that area. Now what, I do not know how well they are documented but there have been reports of them.

I agree with you that the (inaudible) a lot more research and a lot more study in that area.

Jim Howard: I agree quite strongly with Bill. As I say, there are a great many hazardous materials that we are not at present handling, many of which we do not even recognize as existing in potential harmful levels in the environment. I am not sure how logical this may be, but the fact that we recognize the problem exists and have been able to handle it in some cases, to me, does not mean that situation should now be dropped and all effort placed on something about which we know less. Rather, to me, it would mean that priorities established, those we can handle we handle, and immediately trying for research on those we cannot handle, simultaneously.

William Walker: Could I make one statement and then I promise not to say any more? Speaking on the nitrate thing, and what he just said. We have nitrate up to 9000 ppm we found in ground water. Now, we found that trees are centered in this stuff, this very type of soil. We found 6000 ppm in wells that people tried to drink for awhile until it got too bad-tasting. With this kind of nitrate problem, sure, we have a problem with nitrate, but, you know, the veterinarians in some colleges will prove to you that this vitamin A deficiency cannot be traced to nitrate. They will prove to you that scour in pigs comes from something else other than nitrate, or could, and it would throw enough shadow of doubt on it that you are bucking a whole university's veterinary college that has some very sharp people in it. Now then, if you want to go over to another State, they do not agree with us at the university, then you can get agreement, you know, but now, here is the kind of thing we are talking about even with nitrates, and when he says 15 ppm, we do not worry about that. California didn't, they had 45 and they raised it to 90 when too many supplies got over 45. This is nitrate we are talking about now. Now if we start talking about something that is nebulous so that you could argue through subclinically, and even the veterinary experts disagree among themselves, for God's sake, let's get off of some of those things, at least partially, and get on to some of these things we know, for instance, so many parts of arsenic will kill. Let's establish the tolerance levels, somehow.

From the Floor: Some of that nitrate contamination is becoming such a ubiquitous problem. If you look at Texas, nearly every shallow aquifer has nitrate in it.

Jim Howard: You also have many areas which are extremely high in sulfate. There are areas in Ohio which as a basic natural quality, because of gypsum and anhydrite composition in the entire northwestern part of Ohio will exceed the PHS limits. So it is not necessarily a man-made problem. The key is that those factors which are recognizable and may be attacked first, should be attacked first, while priorities are to be placed on those items about which we know least. But, in west Texas, some people consider that the finest quality water, and they automatically assume that if they have half a glass of water they are going to keep a quarter of it (the sulfate) in their stomach for about 3 days.

From the Floor: I think there is some confusion. I said nitrate nitrogen, but now I do not know if that makes any difference.

Thomas Ahrens: I want to get off the nitrate. In Jersey, in our coastal plain, we have some very bad problems. We have what we call the Pine Barrens and they are uninhabited mostly. The big 5000-gallon or bigger tank trucks and trailers come rolling into the State, through metropolitan New Jersey, New York, Connecticut, you name it. They run out in the Pine Barrens, the driver jumps out and runs around the back, opens the valve and dumps it right into the sand. And the next thing, some poor devil who has a shallow well, darned near kicks the bucket. And we do not know what is getting into the ground, where it's coming from, or how it gets there. I do not know whether the other States have that problem or not.

Van Brahana, U.S. Geological Survey, 430 Bounds Street, Jackson, Mississippi 39200: I think this is a topic that we really ought to kick around. The tone that has been going on here for the last 15 minutes or so has almost scared you to death, if you are dealing at all with ground water. It sounds like ground water is verboten. Let's forget it because it is so darned complex. But this particular problem exists all over the country and it is because we in the profession have not really done our homework and have really not been providing any significant input to our States or those kinds of agencies who have been trying to give some attention to these hazardous waste disposal sites. We have gotten so scared the last few years because of the radioactive materials that we quit even thinking about other kinds of hazardous waste disposal sites and we have pushed it off into the closet somewhere. Consequently, many of the industries that are generating these fantastic hazardous materials are dumping the stuff, as you say, in the Pine Barrens of New Jersey, in the deserts of California, Arizona, New Mexico. Almost any time that you go into the back country, where they think that nobody is watching them, you will see these big tank trucks dumping stuff that is just unbelievable. We need very strongly, in this organization, or some organization—and this is one of the best organizations now that could possibly attack this problem—we need very strongly to get this kind of input into these people who must establish some of these highly hazardous waste sites that can be acceptable in terms of ground-water hazards.

Thomas Ahrens: The trucks coming in from New York could not bring garbage and chemicals over and dump them in New Jersey, we need some kind of a law. This law was broken down and dropped out because it was interstate commerce.

From the Floor: To second this, what he is talking about is that we need controls on the management of these hazardous materials because industry is making chemicals faster than we can learn how to analyze them after they get into the ground water.

Texas Water Quality Board, P.O. Box 13246, Austin, Texas 78711: I think all of us have probably had experience in spills, and we all play detective trying to determine the source of the contaminant and eliminate it. But I would like to know if some of you here have had experience in renovating the gravel water. I know in Texas this is a big problem. To see just what we can do to bring it back to its other condition—I wonder if some one has had some experience with that.

From the Floor: Are you talking about hydrocarbons?

Texas: Anything, except for a very small local nature.

From the Floor: Well, we can give you some case histories if you are interested in that. Renovation, in a sense, in terms of recovery of the material. Is this what you mean, how do you get it out of the ground once it's there?

Texas: Yes, I am talking about any ground water that would not come back into the stream, or through a stream.

From the Floor: Well, there are some case histories that are or can be documented. One case that comes to mind is the case of a military fuel tank farm, where over a weekend someone cut the fence, went in, opened all the valves they could get to within presumably 15 or 20 minutes, on all the big tanks. By the time it was discovered, there was something over 600,000 gallons of aviation fuel dumped into the ground water. The water table was, at that location, about 40 feet below land surface; it was in a coastal area which was quite permeable, and fortunately it was on a military reservation where they had sufficient distance and a little bit of time to design it. Within three days, there was a contract let for $600,000 for every drag line that could be found in the area to start excavating interception trenches. The trenches were cut along the downgrade side of the reservation below the tank line. Vinyl chloride film was laid in the trenches at the water table and below the water table to intercept the gasoline which was floating on top of the water table, and for about a year and 3 months, the military continuously skimmed the gasoline back off of these trenches with snifters—everything they could possibly devise to pick the stuff that was floating on films anywhere from one centimeter to 2 or 3 inches thick. All together there was pretty close to $2,000,000 spent to try to recover that gas. All together in terms of liquid volume, they recovered 43% of the spill. The rest they assumed either evaporated or is still locked up in the sediment. Now there are surely several of these kinds of things that would have happened but it can be done successfully if the water table is close enough that you can physically get to it. How you would get to real deep aquifers I do not know unless you could develop some kind of a skimming method. In the middle of Los Angeles, in the southern part, I have operated a Mayhew 1000 for 2 days on the gasoline that I skimmed off of the mud pits when we were drilling a geological exploration hole. This gasoline was floating on the ground water from the middle of that city as a result of spills from the refineries, stuff like this. As far as I know it is still there. But it can be intercepted, it can be cleaned up if you can get to it.

William Walker: Along this line, was there any consideration given in that particular case in Texas to just putting a deep well in and start pumping? And then put a skimmer well on top—it seems to me that $600,000 could dig a big trench.

From the Floor: They cannot get enough volume of the material into the cone to intercept it.

From the Floor: Let me ask about another case history you mentioned a few minutes ago, the gasoline spill where the lady had her pitcher pump. You said there was one company of the 5 that did a lot of pumping for a long time. What type of wells were used? The special wells to skim or existing?

From the Floor: Shallow, large-diameter wells, especially drilled for that purpose. They drilled one down 600 feet.

Jim Howard: There are a number of those. You mentioned one method of approach. What Bill was talking about [illegible]usable very nicely in a homogeneous system wi[illegible]y coarse gravel where you could set up a parasite well system. It can also be done in solid rock wells under certain types of conditions. I could give a couple of case histories. In terms, for example, those of you who heard Osgood mention fracture systems—you were probably thinking about rock fractures or joints. He was not talking about rock fractures or joints. He was talking about zones of high-density fractures and this is a case history of one of the cases we have covered or handled last year. The situation involved a gasoline station with a single pump that provided pressure in the tank for the batteries of pumps around the station. This fellow had what I call an ideal system—he had a valve blow. They did not know it and lost 5,000 gallons of high octane gasoline in the ground. Now, the geologic system in the area involved had about 8 feet of glacial or alluvial material with low permeability over shale bedrock. The ground-water system during normal conditions was such that it moved below the alluvial material into a storm sewer, because of existing relatively high relief. Then it rained. They did not know the leak had happened until it rained. It then ponded and appeared to move upslope about 600 feet where it intercepted a water well which had a defective casing. At that point it dropped 60 feet to a regional water table and began migrating along 2 separate directions of fracture patterns. That loss was recovered and handled in 3 months by knowing what the system was. Interceptor wells allowed recovery of water quality to a point less than one quart per million in 3 months. They properly located, analyzed the system and handled it, which was good because the area in which that spill took place has 500 houses on private wells, 2 churches, a high school and a grade school, all of whom were fed by water wells. So it can be done if you know, or have some feel as to what the mechanisms or hydrologic controls are. It is not perfect. Out of that 5,000 gallons we do not know how much went down the sewer. We recovered about 2,000 from the ground waters but the ground-water quality was renovated to a level where all wells, except 2, were renovated and able to be used. The others were handled by double casing and sealing off the upper zone of contamination and recompleting wells about 30 feet deeper. So well construction and handling can be a factor of technology with which we should all at least have some familiarity. That was my point. We share what we know and make sure that people know we are doing it, as a profession, whether it be NWWA or as geologists or engineers or hydrologists, we have to handle it. We are doing them a favor and ourselves a favor and laying the groundwork for the next level of research and activity that we are going to have to hit. Because if we do not hit it, and we do not make a noise, then there is nobody going to hit it until somewhere half a city is going to blow sky high or you are going to lose half a county of people. And actually, I guess in some places, we have almost lost half and it never did receive enough publicity. And if we have done it already, that makes me even worry more.

From the Floor: You mentioned just briefly about tank trucks hauling hazardous waste. Do we know what this material is? Do we know what effect it has on the ground-water system?

William Walker: You try to get an analysis of some of the chlorinated hydrocarbons, they cost $50 to $100 or so for an analysis, if you can find a laboratory that can do it and then it is very hard, but there are a few that will identify those accurately. Universities have most of these laboratories. We did a survey not long ago on laboratories in this country, of the ones that could take virological, radiological, biological, and chemical. There is not a laboratory, commercial laboratory in the country, to my knowledge, that can analyze all of them—no one. So here is a problem that we are running into, you can distill some of this junk, you do not know what the junk is, trying to find out what it is so that you can trace it back to the guy.

From the Floor: Generally, you do not know what the actual material is that is being dumped because it is being dumped illegally and therefore no one is going to tell you, even if you catch them at it redhanded, and unless you have the authority or you are an authority that has some controls over them, they are not going to do anything. As he says, the ability to analyze the material once it is in the ground and you get a sample back out, is extremely difficult to find. There are very few laboratories that have that capability so we know that it is highly concentrated industrial waste. We have in many cases, and I can speak only for southern California, southwestern part. We have taken samples and analyzed for the trace metals, things like this, and have identified the highly toxic material. We do not know what the original material was that was dumped. We do know that it is this classic material.

Robert Minning: O.K. How do you perceive that this can be regulated?

William Walker: One possibility that I would like to suggest would be to make it easier for the industries that must get rid of this material to have an approved place to dispose of it. The problem largely comes from the fact that there are not sufficient properly approved disposal sites that are economically reachable by some of these industries. In California today, I think there are only 13 approved, so-called Class One, dumps and of those 13, there are at least 4 that are either shut down or about to be shut down because it is now determined that they are at the wrong location, and that they are hazardous to the area; therefore they may no longer be used. When you start thinking of the 600-mile length of the State of California and the distribution of industry in this, and if they only have 8 or 9 Class One dump sites, most of which are in the southern end of the State, there are many industries that just plain cannot reach those dumps. Therefore, they are going to dump this stuff, get rid of it some other way. It either goes into a stream or goes into somebody's sewer through an illegal connection, or they are going to haul it out and dump it at night in somebody's pasture. That is the major problem.

What I was trying to say awhile ago is that we need as an organization, a profession, to provide more assistance to our local governmental agencies to, hopefully, provide the capabilities to the industries that are generating the economy of the world that we are all dependent upon, that have the ability to dispose of the materials they are generating. What we have got to do is to decide which hazardous wastes can be stored, and which needs to be disposed of. And it becomes incumbent upon us, hydrologists, geologists, to help as waste managers in identifying and selecting hazardous disposal sites. Storage sites are not too bad. Disposal sites get into the environment and are lost forever.

From the Floor: One thing, I have noticed, is a 2-pronged program that we are trying to develop. One is to develop an inventory of all cases of hazardous waste spills that are actual public health problems, and those that are potential public health problems. And secondly, once the inventory is developed and we have the proper strategy, we hope to recommend those sites that could be usable perhaps as hazardous waste disposal. I am sure that all of us are interested in the same subject, and if anyone here can get any of this information to me or to anyone in the EPA, we will channel it the right way, to try to develop a proper inventory. We do not have any legislation right now on the books to control hazardous wastes in any way, shape, or form, and right now it is very low-key effort. Right now we are working on developing inventory; we are not trying to point an accusing finger at anyone. But we would like to get a good handle on this, and I know one thing, myself and other people will be on the phone trying to talk with people that have knowledge of this problem and try to develop a good case history study of all these problems that have come up. So if you get a call from me or from someone else, this is what we are trying to do, to develop an inventory. Try to keep track of what is going on in the country and make a logical approach to it. But right now it is very low-key. I wish there were legislation but just from the lack of knowledge of the subject, it is treading on very thin ice, let us say, to even suggest legislation at this time.

Greg Stockert: I would like to know how much constitutes a hazardous spill. I have a case study right now. Two years ago a small town called Dundee, Ohio, population around 600 people, had one gas station and then they had a State supply plant where they cut salt out in the open, where they let the salt go right down into the ground. On the complaint of the people, we had a client talk to us about how they had some kind of a foul smelling water that irritated the skin. And we had originally drilled a well in the alluvial type of (inaudible) and when we tested the water, took it to the State Health Board, it came back as an ethyl (inaudible). And we started to further investigate it and found out it was going to the gas station that was no more than 50 feet from the house, so obviously it was leaking through whatever kind of tank they had it in. The client was quite upset and called the State Health Board about anything that she could do to get something to pay for her new well that we drilled deeper and that type of stuff. Then she got to thinking about all the other people in this small town that have wells by their houses and I started to say that we cannot fund a study, we cannot do a study without some kind of money, and she went around the town trying to get some kind of money together. The people were rather lackadaisical about it. Now 2 years later, they haven't done anything at all. But about 2 or 3 miles south of the town, they have called in a big contractor to install a city system. But yet they are not going to plug those wells up. Those people are still going to drink that water or have it on their lawn, or something like that and it is still going to migrate.

Jim Howard: One thing I would like to throw out. Now tonight this is what is called a bull session. Having been a college professor for 6 years, I have been to a great many bull sessions, but we never accomplished anything. Would it be possible as a bull session to provide some positive input toward policies, activities, considerations or evaluations, to the group in which most of us or all of us are members, as to what we should do to tackle some of the problems? We have had 2 so far, one State operation capping wells and the second—some of us feel is more important, it may not be in other opinions—hazardous materials. Can we not use this bull session as a positive method for beginning something?

Robert Minning: That is a good point. Can we do something to make it worthwhile, as a group? Because I think there is enough expertise and experience in varying fields, government, consulting, State, whatever you wish, that input can be generated and directed toward a useful goal, which we may not reach this time. Can we start something to make worthwhile all our discussion, debate? I think it is possible. I think we all have our own ideas as to what can be done. I would appreciate hearing from some more people involved in this.

From the Floor: I have been employed by private industry for about 6 years. I have seen the bull sessions there too. And I am struck by the tenor of meetings like this that I come to, the tenor being established by people from government agencies, and from universities and State agencies, from papers presented that are largely from those people. The industrial types, which I can understand, do not say very much. They ask questions but they do not contribute. I have counted the papers that are being presented. There are 20 papers here and 2 are being presented by private industry. Now I have learned a lot tonight; I have heard a number of cases from consultants. If perhaps we could hold a section on ground water, very brief in case histories, where industrial types can publish this information without divulging the confidential information itself. So perhaps one concrete thing that could be done would be that. Because I find it very informative to hear from people who normally do not have the freedom to speak up.

Robert Minning: That is a very valid point and I will say this, last year that very topic was discussed in terms of ground water. Trying to get some case histories developed through consultants, private industry, anyone engaged in a project could say, look, I have this problem and this is the way I solve it. I used these techniques. It is only as good as the people who submit papers, and the majority of the people who submit papers for publication are the same majority of people that we see here at the convention, mainly this is their profession. I would say people engaged in government work, they are engaged in a study and the culmination of that study is a report, and the report is subject to publication. That is not the case, I do not feel, in the private sector. Certainly, you culminated the study but that study is not written for publication.

From the Floor: I agree, exchange of information is the only way we are going to progress.

From the Floor: It takes time to write this up for publication, time which means money for the consultant. But I would wonder if a section on ground water for case histories with a limit of one page would require too much time. If a consultant can do that he would not have too much—

From the Floor: It is something, I think some of the international pollution journals have letters or short papers, and some mechanism for letters or short papers could be put into the journals, even if it were on an information basis—it would probably be a sufficient measure dealing with these case studies.

Jim Howard: But several things could happen. A client will quite often consider the entire project as privileged information, which is why the client is involved. After a series of cases, I could give a model of what happened and how we approach it. I cannot give specifics of where, when, who and so forth. But there was one paper, I'd like to mention, in yesterday's session of NWWA—it was a government paper, a USGS paper. It did not say it was completely successful. It said what they tried and what did not work and why. Most papers only publish that which worked. You know, nobody wants to know a failure, be it a government man or a consultant, it is money in the bank, his reputation, or whatever you live on. But if you can go into something and tell what happens and why, nobody is perfect. That paper except for a few master's theses that I have read, which by now you are saying they had to make a negative result, but that paper to my knowledge, in about 15 or 16 years of listening to papers, giving some, and writing others, to me was the first one I have seen which has the raw element of reality. We tried this, we spent a heck of a lot of money on this, it blew up, do not try this there anymore. I agree. The company I'm with is considering a policy that every man, over project manager and above, will be required each year to publish at least one paper that has releasable information or a summary of information that is not confidential. We have not adopted this but it is in our philosophy whether we do or not. This means that in my company a man could write that paper. Each paper is going to cost us, just in man-time alone, a minimum of $2,000-$3,000, just for my company alone. Until the profession decides that it is worthwhile, as a professional obligation rather than a business obligation, to maintain and develop technical cooperation, this procedure will be difficult to implement. And if we do too much of it, it is possible that we may not be in existence next year. But, I mean, it is a feasible element. That is money out of my pocket. The profession as a whole most decide, because we are professionals. The argument with which most of us have been attacked is the fact that we are not a profession, we are an avocation. We are not scientists. Physicists and chemists feel that we are not scientists. Engineers feel that we are scientists. So we are somewhere in that nebulous half-world. And until we begin to prove that we are professionals by both contributing to society and contributing to our profession the technology which we develop in our own unique sessions. And add, to a certain degree, the engineers who deal with the same system. Then we are going to be second rate, out in left field. We are going to be called in as a last resort, when it is too late to do anything much.

Robert Minning: It was mentioned that perhaps we can provide some positive input as a group to ground-water pollution hazards, and we have heard from a few people here. There are obviously some more people here in the room who have had some experience with lesser known ground-water pollution problems or hazardous wastes, who have done something about it or at least been involved in some type of regulatory activity towards some kind of recovery process, study investigation. I would ask that you share these with us. How do you solve hazardous waste problems? What were they? Is there something that you could not solve?

From the Floor: I would like to suggest one thing. One other topic that might be worthy of discussion. This relates to our ability and procedures for actually sampling or keeping track of certain kinds of unusual waste disposal activities that may seem very innocent, but suddenly we find out that we have a real problem.

One of the major problems we are faced with in our business is trying to identify various kinds of chemical compounds in the ground-water resource. What are the concentration levels that we are really concerned with in terms of the specific compounds and how do you actually tool up to make sure that you can sample in a manner that will give you analyses that have any acceptance or any validity? Now, let me give you one example, just to illustrate my point.

In some industrial processes, it is necessary to steam clean metal parts that are coated with or that contain rather exotic nitrate compounds. And I am not trying to get back into this nitrate contamination business. The effluent from the steam cleaning process goes into a collecting pond where the solids settle out and are reclaimed and disposed of, but the liquid part of the steam cleaning fluid percolates into the ground water. These nitrate compounds have been demonstrated to be extremely toxic to human beings. Now we have not been able to discover, within the well drilling profession, more than 2 or 3 people in the western part of the United States who are willing to tackle the job of constructing observation wells or constructing or doing drilling into this ground-water percolation environment, in a manner that they can guarantee that they can give us samples that are not contaminated by the drilling process itself, if you are talking in the microgram per liter range. Now I use this as an illustration of some of the kinds of problems we are going to be facing if we are really going to start getting involved in the problems of unusual contamination in the ground-water regime that most people think about.

We have a very broad range of what can usually be classed as everyday activities that are throwing toxic, hazardous materials into the shallow water of the ground-water system, that many, many people are dependent upon for their individual domestic wells. And the water well industry must develop some better techniques, better attention to the ability to provide samples of the aquifer materials or samples of the water, that they could use with confidence as a reliable analysis.

Dick Rhindress, National Audobon Society, 2501 Garrison Avenue, Harrisburg, Pennsylvania 17110: Up until June 1, I was with the Pennsylvania State Department of Ground-Water Resources, Pollution Control Group. In answer to a couple of your points, it seems to me that when it comes to identification of these complex organics, it gets to be a never-ending thing because I think they are registering something like 80 new compounds a week, and we are up in the tens of thousands now, and Lord knows where we are going. It is hopeless to expect a lab to identify some of these things and the way industry is going, they are not even registering a lot of their compounds. I agree that there is a need for better labs and better services from the labs, and so forth, and perhaps some of the EPA labs certification might do us some good, I am not sure, but that is a possibility. On the other hand, the drillers getting up to construct a decent well for want of water sampling, how we found it in the last 6 years with the State, that after a long hard battle we got one drilling company in Pennsylvania to come around and really start getting serious about doing this kind of work. It was sort of a partnership, we asked them and they helped us, we helped them and we finally got there. But it is an education problem. If I can back up now a little bit, it is his company by the way (Jim Howard's company). If I could back up, we were talking when I first came into the room, about hazardous wastes. To me there are 2 kinds. There is the accidental spill and there is the other kind, which is the waste which never should be thrown away. We have got to stop throwing things away. There ain't no "away." It is always here on old planet Earth. Unless we can put it in rockets, send it that way. We have got to stop talking about throwing things away, hiding them underground, all these sorts of stupid things. We have got to recycle, back to the old word and there is a big generic word for recycle, but there is only so much left on this old planet Earth. We cannot deal with it, we shouldn't have to be worrying about deep injection wells to store, that is a nice euphuism but I do not think we are really storing, I think we are throwing away stuff when we talk about deep injection wells. We have got to get off this kick. Somebody today, made the point that we ground-water people have got to get a unified law, not a surface law and a land bill law and an air pollution law, and so forth. We have got to have a unified environmental law so that ground water, which is about the only one left, does not take it all. We have got to have it. I am in ground water and I have been for about 8 or 9 years, and I still will be even though I am in conservation.

From the Floor: What do you mean by drillers not sampling properly? Is it, would education help? What do you mean by a sampling? Would you be more specific? I would like to know because I am in a company which does this type of work.

From the Floor: They do not have the equipment nor do they have the inclination or the training to understand the actual geology of the subsurface and the need for certain types of procedures to get materials that will yield analysis, yield determinations within these kinds of concentrations.

From the Floor: I will skip over this and backtrack to our gentleman from the Audobon Society. I did not identify myself the last time that I addressed the floor, but my name is Ralph Preble and I work for the consulting firm of Camp, Dresser and McKee, One Center Plaza, Boston, Mass. 02108, and at the present time, we have a company, a private company, backing us to the tune of about two billion dollars for the complete recycle.

From the Floor: I have been wanting to say something. The fellow sitting right here, coming up with all the problems we have had to deal with as well drillers and we work to try to solve them, but if the engineer hands me a piece of paper and all he asks for is a bid, he doesn't ask. I put on the bottom the last few words—no guarantee as to quality or quantity. I will put in a hundred new casings, drill a thousand new holes a year. But it is up to you people and geology experts to tell the engineers, let them know that they are responsible.

From the Floor: I would like to go back also to the man from the Audubon Society. I also am a member of the Audubon Society, incidentally. I agree with him that we have to start thinking of waste in his terms, but I have heard this from environmentalists and others for quite awhile, and it takes time to start new techniques and I am sure you will be working quite hard because the less waste they have, the more problems they make. So we have to consider that there is going to be a lot of waste generated and have to be disposed of certainly within the next generation and I think the injection well has a place as one of the methods of waste disposal, particularly for radioactive wastes. It is very good for malodorous waste or for certain refractory waste. I think the important thing about injection wells is proper regulation. I believe our State has it and of course, I happen to be the one who administers the law. But I think we do have a good law and we have a good method down there. We do not, as the gentleman said this morning, use it as a last resort, so to speak.

Bob Scott: We need to know more about the fate and behavior of the waste we put underground and on Audubon, there have to be exceptions. Your generality, you cannot color everything. For example, on the Snake River plain in Idaho, we are encouraging (inaudible) to inject attriated water, stripped of all other radionuclides. The reason we try to surface dispose of attriated water, it will come back to you in rain or snow (inaudible). It has a half life of about 12½ years. Which means if it moves 125-250 years it is gone because it has decayed. Put it into a ground-water aquifer, it is going to be feet per year instead of feet per day. In some of the deeper zones of the Snake Plain aquifer, by the time it discharges you will not find any tritium in it. Some of your organic wastes may have similar self-destruct capabilities, so know your wastes before you put them underground.

From the Floor: When a geologist comes in or a State agency contracts a drilling company, it seems to me an awful lot of the time that the State agency is way off as far as thinking he is above that person or that drilling company. There is a real friction developing between the two. Now, a lot of the time, if that friction is strong enough, that driller does not care what goes on in those samples. I would say that if anybody works, and everybody does, with drilling companies and stuff like that, that through common talk, and understanding, that he has a job that is just as important as what you are doing, then things would come off good, and you would have a good friendly relationship. Then things will go the way you want them to go.

Dick Rhindress: A lot of things we found in the State agency, when I worked for the State of Pennsylvania, was that we just about had to hire people straight out of college with zero experience, because that is the level of pay that civil service would let us give. Where are you going to find a guy that is experienced in drilling and everything else at that point? I would make a suggestion to any one of you that is with a State agency, that you start running the people through the NWWA driller courses. They are not too bad. I should have taken them on the side on my own, just to beef up my own education so I can talk intelligently with a driller. And it would not hurt at all–I know everyone on the staff of Pennsylvania at the time I left, sure could have used them.

Jim Howard: I do not think the company that I am with is probably unique in the country but it is an 85-year old drilling firm that now has 23 geologists in it as a consulting component. One of the things in the NWWA, as a profession, that we are not using is the fact that–I will give examples. I can go out to our drillers and say, hey, I have got to get this from there and I need it in this form. And he says why? And I tell him why. I would venture to say that most engineers or most geologists walk out to a driller, federal or State government, and say I want to have this from there, you do it this way, he would say Yes, sir, as long as you pay my check. In our company, we have a relatively unique situation. We sit and drink beer and throw the bottles at each other. If I want something done and it is feasible, then I can get a driller who has 20 years experience in finding a way to help me do it. As long as we think, as geologists, that we are superior because we have been to college, for 10 years in my case, and because of that education, we are not ready and willing to ask them for help, rather tell them what we want, you are going to wind up exactly like a computer program, garbage in and garbage out. Until we recognize the fact that we have to work as a team in every case, every category, where we use what we know and where they can provide what they know, we are going to wind up arguing whether deep well disposal may or may not be feasible, whether the sample we got was from this method is worth a darn versus this sample. And the basic contribution that we can make as a profession and as an organization is to begin to integrate what we know, how we know it, where we know it and in any way we can get it. And, another thing, we are going to have to take the initiative, because the drillers look to us, I speak from experience, as know-it-alls who are telling them their business. The best contribution we can make is to try as an organization, to blend. That means to stop being so egotistical as ourselves and recognize that other people can do some things better than we can, whether we are engineers or geologists.

John Logan, Hillsborough County Water Resources, Box 1110, Tampa, Florida 33611: I came in here to listen to lesser known hazards but this actually is of great interest to me. I have to say that I have just heard some things that are quite obviously not true. We are working with the drillers. We are not superior. We can all prove it with the fact that we are not members here of the American Association of Ground-Water Hydrologists, we are here as members of the National Water Well Association. We are a minority group and we are in it voluntarily because we need to work with drillers, we have over many years and the drillers have worked with us. There have been notable advances. There are more to go. But the original charge, I think, was quite well founded. It was not a charge against drillers, it was a charge against drilling technology. And this is true, if we cannot sample in the microgram range, particularly, and this is the fault because we do not have the methodologies to do it. We cannot sample 3 inches below the ground and get an undisturbed sample. It is a phrase that exists in the textbook but we all know that we cannot get such a thing in the microgram range, particularly done at 2,000 feet. Maybe, in a generation, we might know how to do it but we certainly do not today. But the charge was not against the drillers. It was against the technological methods.

Bob Scott: I would say that the better drillers belong to NWWA. The best ones are here at this meeting. We still have some (inaudible) in some areas in some States on the less cooperative productive drillers.

Bruce Yare, Woodward-Moorhouse & Associates, Inc., Clifton, New Jersey 07012: In terms of analyzing the contamination induced by the drilling method itself, you have to analyze the drilling methods in themselves–you have to compare the advantages and the disadvantages of each technique. As you associate with drillers you become accustomed to their ways of drilling, the techniques that are used and you evaluate them in terms of the type of sampling you need to perform.

In my paper I have compared the technique of jetting, cable tool and hydraulic rotary–the advantages and disadvantages in terms of obtaining in situ water samples. One of the things which should be avoided is bentonitic drilling mud because of the possible adverse effect that these muds may have on formation water–in particular the absorption of particular chemical species by the mud itself. To overcome this possible drawback, we use an organic based drilling – Johnson Revert.

Prior to starting a drilling program a decision must be made on the particular type of samples or the use of the samples that they are going to be put to and then in light of this information, a particular drilling process should be used. A great deal of time, effort and money is involved in determining whether or not the samples you obtain are from a known horizon. In the paper I presented yesterday, we used a cluster of wells to establish that these samples we obtained were indeed from a specific horizon. In order to do this we used a cluster of wells with one center well and 5 peripheral wells. The 5 peripheral wells were completed at depths of 20, 40, 60, 80 and 100 feet and provided water samples from known horizons. Samples from these horizons were compared to samples obtained in the center well by our drilling sampling technique, developed in the course of our investigation, were indeed representative of in situ ground water at a specific horizon. This comparison for establishing that these samples were indeed from a specific horizon or was representative of a specific horizon was an extremely costly and indeed time-consuming technique. This well cost approximately $5,000 but in terms of establishing that the samples were representative of in situ hydrochemistry at a known horizon, it was an invaluable and necessary procedure. This type of comparison is indeed necessary to establish that the samples you obtain are indeed what you say they are.

Bob Galbraith, Kennecott Explorations, 2300 W. 1700S, Salt Lake City, Utah 84104: I was under the impression that last Friday we took samples from parts of the (inaudible) in Arizona and I was wondering how you could determine that they were not contaminated, the sample (inaudible) on the basis of conductivity.

From the Floor: I do not know of any better way, and I do not know how you are going to prove that what you got was what you were after.

Bob Galbraith: This is part of the problem. There may not be a better way that we know of now until we look for it.

From the Floor: If you find the answer you are looking for you were right.

Wayne Pettyjohn: One of the problems is how you find an undisturbed sampling, as I understand it, and I am fairly new to ground-water work. I am a geologist. As I understand it, the criterion is usually conductivity. Is there any other standard criteria you could use?

Donald O. Whittemore, Kansas State University, Department of Geology, Manhattan, Kansas 66506: I am involved in a project where I am looking at trace metals at background levels, presently, in preparation for seeing what happens when a large coal-burning power plant begins to start its operation. I would be very interested to see a study where somebody used standard drilling techniques and actually analyzed some of these different trace elements to establish what sort of contamination you could expect from the standard drilling technique. Has anybody done this sort of study–just on the drilling technique itself and what sort of contaminants are produced?

Wayne Pettyjohn: I am coming in in the middle, so I do not know what is going on so I will probably put my foot in my mouth again, as usual. For the last three years, we have been conducting studies on heavy metals in surface water, ground water and (inaudible) site sediment, as well as public supplies and I think the scare of heavy metals is gone overboard. I do not think that there is nearly the significance here that many of us think there are. We have analyzed over 10,000 individual samples and rarely in the water do we find enough that is even measurable. And furthermore, we did one sort of interesting study, looking at certain heavy metals in tap water. And we found that in a faucet that had not been used for somewhere between six months and a year, that if you turned it on and collected the sample immediately, and it was an old plumbing system, that the content of zinc, copper and lead would be quite high. In one example, the tap in my office, the lead concentration was about 10 times above PHS limits. Of course, that attacks the brain and I drink that a lot, which explains something. But, anyway, if the tap is allowed to discharge 2 minutes, at least we collected samples after 2 minutes, and in nearly every case the concentrations of these things dropped down to a level that was not detectable. So the point I am trying to make is, when we find a sample of ground water, or surface water that contains a lot of metals we are looking at a very exceptional case, gross contamination or very weird geochemical conditions, and under the natural conditions, there generally is not enough to even worry about and we are getting more from drinking beer out of cans or water out of the faucet, or coffee out of a pot or coffee out of a dispenser, than we are from normal ground waters. Did I put my foot in my mouth?

From the Floor: There was a recent article in *Newsweek* that suggested that some work done at Dartmouth would require that you flush your system out in the morning with the first cup of coffee. We are finding problems with salt waters. It seems to have greater leaching power than the hard water. And we have a problem in the Pacific Northwest where some galvanized type of (inaudible) reacts with the cutting fluids, releasing large amounts of heavy metals into the plumbing system in houses of subdivisions. There is work being done by a private water company in San Jose, in their own lab, to indicate that lead can be caught into the water system through galvanic action where they solder the joints of the copper tubing. The drinking-water standards are set up for lifetime ingestion. If you take that first cup of coffee and your 10-minute flush including that, cleans your system. You are building for the rest of the day. You should not be getting a lifetime exposure. If you drill a well into an aquifer that is getting this material continuously, then you may get a lifetime exposure if you stay there the rest of your life. So there can be a difference between the 2.

Wayne Pettyjohn: I will agree with that. But in the samples that we have run, and obviously I have looked at a very small area, in none of the samples in this 8,000-square mile area did we find enough lead to even register on a machine. And another thing that has bothered me, when you talk about limits in water, people do not drink any water. That is a rarity. They do not look at the amount of lead that you find in a can of tuna fish or in beer. It seems like we have another double standard. The first double standard that has always bothered me is that we expect surface water to be contaminated so we chlorinate all supplies. We find a well which shows up with a positive coliform test then that has to be taken off the line; it is a bad scene.

From the Floor: But we in the water business try to protect the water to our standards, hoping that the FDA protects the food. The total ingestion, the total volume, is less than what is toxic to the human.

Wayne Pettyjohn: Well, there is another little problem. We really do not know what the significance of these things are.

From the Floor: Some of them.

Wayne Pettyjohn: Well, I would say, a good share of them. Now, for example, we have a limit on chromium, and I did a rather extensive research and I really could not find much of anything. And then Schroder comes out with his book, *Trace Elements in Hell*, or something like that and he says the major thing we are lacking in our diet, and the reason that we are in such poor physical shape, is because we do not take enough chromium. So what they are trying to do now is find some method whereby the chromium can be absorbed.

From the Floor: Sure, there might be an optimum chromium ingestion concentrate. Like we have fluoride for teeth.

Jim Howard: I am going off after this one. Awhile ago there was a question brought up. Now, I think the statement Bob made which led up to some of this was "Something should be done or decided that we could make a positive contribution," because we got sidetracked into 3 other areas there, quickly. It is easy to do. I think that Bob's group, or this group, should make a suggestion about that contribution.

Now, I am going to spread some hot air in other areas, but I would say that, other than being chairman or something, that if I could be of any help if you decide something, I would be more than happy to do so.

Robert Galbraith: I want to add to his comments about using Revert for elimination of one of your sources of contamination. We have found, in our investigation of how to take these samples without contaminating (inaudible) final analysis. The lubricants that the drillers use on their pipe joints are one of the various things as far as metals are concerned, that you never want to come across. There are some teflon products, lubricants, which have an analysis printed on the label, and I forget the brand name right off hand, that can be used to avoid a large part of this problem of introducing trace elements. The other big problem we ran into was just drippage of hydraulic fluid, grease, oil, what have you, off the drill rig, and this stuff getting into the mud around the hole and getting kicked into the hole. This sort of thing, we need to clean up housekeeping, but you cannot do too much of it.

Jim Rouse, U.S. EPA, Field Investigations, Bldg. 53, Denver Federal Center, Denver, Colorado 80225: I have been involved in some work in Florida which involves an unknown ground-water pollution problem which should not have been unknown. This problem revolves around radium pollution resulting from phosphate rock mining and milling.

Everyone has known for years that phs rock, especially Florida phosphate rock, contained uranium; that was one of the prospecting techniques used to find the uranium. When the phosphate rock is reacted with sulphuric acid the Ur goes with the Ph fertilizer but the radium, the K product of Ur, precipitates with the by-product gypsum.

As far as I was able to find, there was only one sample which was ever run for radium in phosphoric acid plant waste, although radium was commercially recovered from phosphate plants during the 1950's. Work we have done reveals the liquid water from Ph acid plants contains 100 picocuries per litre of radium. This is from 3 to 30 times any possible standard for radium in water. We have found approximately 400 square miles in central Florida contain high values of radium in the shallow ground water. At least a portion of this appears to result from the mining and milling of phosphate rocks to produce phosphate fertilizers.

The by-product, gypsum, derived from Ph rock mining and milling is extremely radioactive and many people are now proposing to use this material for construction of wall-board. Such use would expose all those living in houses containing this wall-board to high levels of radium decay products. This raises the spector of having a Grand Junction, Colorado situation being scattered all over the world and I would think that is something we need to speak out against very strongly.

John Logan: I am Water Resources Director for Hillsborough County and we just permitted some 28,000 acres of phosphate mining. The phosphate ore of west central Florida contains enough U308, I remember is the basic (inaudible) of the Atomic Energy Commission and Geological Survey of the 1950's spent several millions of dollars in a very large program to see if uranium could be extracted as a by-product of phosphate. Now we are going to tear this up, recycle water all the way through it, develop an increased solubility, and get them into our ground waters a little farther to the west of the problem Mr. Rouse is talking about. It is going to go into the Florida aquifer, probably, which is one of the most productive things we know in the United States. And I am worried as hell about it and I want to see you right after this meeting.

Bob Scott: If this is in a sulfate effluent, radium sulfate has a lower solubility product than barium sulfate, how are you going to get it into your ground water?

John Logan: The sulfate is part of the chemical process of making fertilizer. It is not part of the mining process, because we in Hillsborough County are not going to permit any fertilizing processes. We are just putting up a steel wall around our county, and this can happen in the neighboring county. We are downstream, unfortunately.

Bob Scott: Then the radium would come through in a soluble fertilizer form, not remain in sulfate in retainage ponds?

Jim Rouse: What we do, Bob, is the liquid is an extremely acid liquid that is used for transporting the gypsum. And this will during the recycle be built to an equilibrium concentration of about 100 picocuries per litre. We do not see high values in the mining operation, except during slime pond failure. The slimes are hot. The last slime failure that occurred released about 16½ curies of radium to the receiving bay.

Bob Scott: Also it is in the particulate in a solid form.

Jim Rouse: The bay is now at mpc. And at maximum permissible concentration. We are seeing wells in the mining/milling area as high, the highest value we have seen is 79 picocuries per liter.

Bob Scott: Is this dilution down to mpc or is this desorption? (inaudible)

Jim Rouse: From the dissolution.

Robert Minning: Wayne, did any of the samples that you took to be analyzed for heavy metals come from areas of metal ground-water pollution?

Wayne Pettyjohn: Well, in this particular study, we collected samples from most of the municipalities and some industries and some private wells. Right offhand, I just cannot remember. There was a problem of contamination undoubtedly, in some of them, but most of them were related to surface-water contamination. Plating metal wastes, Fort Wayne, Lima, Findlay, and some oil refineries, things like that. But I cannot recall offhand significant ground-water contamination problems in those sites. But the study is continuing another 3 years.

Robert Minning: (inaudible) concerning sludge remaining on the ground. Have you had any more work with that in terms of heavy metal?

Jerry Hill, Stremmel & Hill, LaFontaine, Indiana: No, I do not have a report here. It will be available.

Paul Plummer, Miami Conservancy District, 38 E. Monument Ave., Dayton, Ohio 45402: Talking about lesser known ground-water pollution hazards, I would like to know if anyone is doing anything on trace organics, particularly PCB. I think it has been shown that there is a significant quantity of PCB in the environment. To my knowledge, I do not think there has ever been any work in terms of whether they are in the ground water.

Bob Scott: Can you find out if they are being leached out of a plastic pump? I think it was announced in the paper recently, on a recent speech by Russell Train, that they would be looking at these types of organics in drinking water. If the drinking water has a ground-water source, you would be looking at it there.

Robert Minning: Does anyone else have a project?

Wayne Pettyjohn: How about a motion for adjournment?

Bull Session — New Technology for Ground-Water Protection

Session Moderator: Richard H. Pearl, Colorado Geological Survey, Room 254, 1845 Sherman St., Denver, Colorado 80203.

Dick Pearl, Moderator: This is the Bull Session on New Technology for Ground Water Protection. However, I think it should be titled the same old thing, New Technology.

Let's set some of the ground rules right now. We've got a court reporter over here. The first time you get up to speak, identify yourself and your affiliation, and next time you get up to speak just identify yourself. It's informal. Take off your coats, your ties.

I don't know where the rest of our panel is, our speakers. There's two of us here, so rather than all the questions coming this way, let's have the questions going every which way. So if you've got anything to say, speak up.

Well, let me throw a question now to Bill Weist, since you reported on your studies of the Indianapolis landfill yesterday at the technical session of NWWA. Have you done any modeling?

Bill Weist, Jr., U.S. Geological Survey, Indianapolis, Indiana 46202: You mean the modeling of the landfills?

Dick Pearl: Right.

Bill Weist: No, we've not done any modeling of landfills. We are working on modeling of the hydrologic system of the Indianapolis area. This is for a different study. This will be an analog model rather than a digital, because we have multilayer drums.

Dick Pearl: Have any of the rest of you been involved in modeling of pollutant, effluent waste fronts moving through an aquifer?

Bill Weist: Lynn, was your model of a fairly homogeneous aquifer or a heterogeneous aquifer?

Lynn Gelhar, New Mexico Tech., Socorro, New Mexico 87801: Well, the system we are representing, I would say, was highly heterogeneous—maybe a hundred different aquifer units. That's a regional representation and just average conditions. It's not in the classical sense an individual unit.

Dick Pearl: I'm not familiar with all your work, where you're from or who you are. Maybe some of you could state what you've been doing in your areas with new technological advances that are being used for ground-water protection of the aquifers from waste disposal sites, gasoline spills or any of the other things that we discussed today.

One of the things we have done here in Colorado to try to tie down the culprits of gasoline spills—the State Health Department now has assigned a specific dye to each one of the major oil companies and their gasoline has to contain this dye. So when we do get a spill all they have to do is go out and take a sample, take it back to the Health Department and run it through an analyzer and it can pretty well tie down which gas station it may have come from. That goes a long way toward solving some of these problems that occur when gasoline shows up in ground-water sources and you may have 3 or 4 gas stations on the same corner.

Lawrence Peters, Dept. Fisheries and Environment, Water Resources Board, P.O. Box 6000, Centennial Bldg., Frederickston, New Brunswick, Canada: We've run into the very same problem where we have open sources. Just how much pressure do you have to put on these people to get such a thing as a dye and what sort of concentrations do you think the dye ought to be?

Dick Pearl: I can't answer your questions. However, I don't think there's been much pressure brought upon the oil companies to accept this dye method. I knew the Health Department had a way of pinpointing which gasoline stations the leak was coming from. I just heard about it today, that they were putting in dyes. So it wasn't enough of a controversial issue where it got in the newspapers. So they must have been able to do it with a minimum of arm twisting.

Lawrence Peters: We have a problem of fixing a source. We usually get a complaint about gasoline or whatever in a basement or in a well. Do you know of any new methods that can be used to fix the source of the gasoline other than digging a mighty big trench?

Dick Pearl: A lot of times all you have to do is look through the gas station's tax records. You laugh, but there's one station that I've been involved with, that put in for a tax rebate because it didn't sell as much gasoline as what its record showed. The station lost about 5,000 gallons of gasoline. So he asked for a tax rebate. Well, they had him pinned right there. He must have been losing gasoline. The nearby damaged homeowners sued and took him to court. The case was settled out of court.

Lawrence Peters: We have trouble getting any kind of settlement. Our policy up to now has been to try and solve it by civil action between the plaintiff and the polluter, but we haven't had any real success that way. I'm interested in what goes on out here, for instance.

Dick Pearl: Well, this one instance that I'm familiar with is the only one I've been called to testify on. The damaged parties were quite successful on it. I think the out-of-court settlement required the oil company to connect the damaged houses in question up to the city water supply. Surprisingly, while they were part of one of the suburban towns here in the Denver metro area, they were using water from a shallow aquifer, which had all kinds of horses and everything running over it. This was no place where they should have been using water wells. It could have been polluted just in the normal course of events. Also, the city main ran almost through their front yard, but they didn't want to hook up with city water. Well, the company hooked them up to the city water as part of the settlement.

Lawrence Peters: Talking about technologies, have you found any good method for casing out gasoline? Do you have a standard technique which you recommend?

Harlan Erker, Division of Water Resources, Room 300, 1845 Sherman St., Denver, Colorado 80203: We do not specifically deal that much with gasoline. We do deal with pollution occurring in some shallow aquifers. We have a policy of requiring solid or blank casing, whatever you want to call it, to a certain depth. There are certain aquifers in the State where we uniformly require so much casing in order to keep the pollution, which is just septic tank effluent, lying on top of the ground water being pumped. It's actually a combination of casing programs and a limitation on the amount of water that can be pumped. If you put a small enough casing in and put the blank casing down far enough, they can't pump enough water to cause a cone of depression down to the perforations. So we do follow that practice in some of the aquifers. We don't have that much of a problem. Gasoline pollution is not that widespread, but we do use this method in dealing with other types of pollution here in the State.

Dick Pearl: It's more in the Denver metro area where this is such a prevalent problem. The gasoline will get into a shallow aquifer, in which basements of houses are constructed. Then the gas or the gas fumes will get into the house. There isn't that great a usage of water wells in the Denver area anymore like there was a few years back.

Lawrence Peters: Well, we're faced with an opposite problem. I'd say the bulk of the rural community in New Brunswick gets its water from wells and probably very shallow wells, and this is a very real problem. Of course, the associated problem of the phenols is quite dangerous. We do run into the same problem that you have with fumes and gas vapors, but it's not as widespread as the contamination of wells.

T. Jay Ray, EPA, 1735 Baltimore, Kansas City, Missouri 64119: A little philosophical question about the modeling—how much practical usage have you seen of your pollution models? Can you give some examples where you can state some inroads?

Lynn Gelhar: Well, the use has been limited to the areas in which we tried to apply them, just because I don't think this kind of approach has been necessarily logical for ground water. We've applied to the estimates of septic tanks, effluent inputs to suburban areas where 4 persons per acre would be kind of a limitation under those conditions. We also looked at the land waste disposal problem in a hypothetical way, and our conclusion was that, at least from the nitrate point of view, it's not as serious as you might think. One of the reasons that we're here is that we'd like to see them used a little bit more. Maybe John Wilson could find out.

Do you have some additional comments on that? We have had discussions with people in State agencies in Massachusetts on the use of it but other than indicating interest there hasn't been any real results from this.

John Wilson, MIT, Cambridge, Massachusetts 02142: The models have been supplied to a number of organizations. In Massachusetts and much of New England the water resources community as far as the State is concerned is not nearly as well developed and not nearly as well funded as it is out in the West. And these organizations have very little interest in modeling of any kind thus far. We have provided the interest but have not been in a position to do anything about it.

Unknown Speaker: When you say they're not in a position to do anything about it, what do you mean? They don't have the funds or they don't have the need?

John Wilson: They simply don't have the funds and the personnel to do anything. Perhaps one might say they have very little expertise. It's a very small operation.

Jay Ray: I'd like to question Bob Crowe. You're going around the country putting on seminars for the training of people primarily in the area of waste disposal problems, primarily addressed to surface water. How much of a sophisticated mathematical approach are you using in your area of technological transfer or when you get down to the nitty gritty of working with the engineering audiences, that I imagine that you have, do you find yourself working on a much lower level? Let's say in this case, mathematics, either because people don't understand it or because in practical situations it doesn't work?

Bob Crowe, U.S. EPA, Technology Transfer, Washington, D.C. 20460: Well, technology transfer up to now has addressed itself towards processes of engineering design for waste water treatment primarily and air pollution control I think it's too sophisticated, or it has not entered into the picture. So we really haven't transfer technology in this area at all.

Drew Comer, State Water Control Board, Northern Virginia Regional Office, P.O. Box 307, Springfield, Virginia 22150: How applicable is your model in areas where values for transmissibility are hard to come by, such as in fractured igneous rock?

Lynn Gelhar: They were hard to come by where we applied the model as well. It's really a range of parameters that one can introduce to see how sensitive the system is to those parameters. So we didn't determine the transmissibility by testing maybe several hundred independent aquifers and different zones. We selected some reasonable figures and it's a question of judgment. The same idea applies if you're interested in just regional information.

Drew Comer: Yes, but I assume you're still talking about a sand aquifer.

Lynn Gelhar: Not necessarily. On a large scale in a fractured system you could have the same properties, response, and characteristics. The transmissibility we used was arbitrary and it was reasonably good, but that's the extent of it.

John Wilson: Conceptually, this long parameter model we discussed has been used in fractured bedrock by some people of the University of Connecticut's Department of Geology, without actually constructing a mathematical model, but rather looking at a conceptual viewpoint and they found for their purposes, it could be fairly good. The model, in fact, has an advantage in such a system where one doesn't have—you're familiar with the extensive models that have been developed by USGS and other various organizations and universities around the country of the finite difference or finite element type. They usually require fairly good field data which one must assume is fairly accurate.

Lawrence Peters: Would you say that your model just indicates a mode of behavior rather than giving actual prediction?

Lynn Gelhar: To some extent you could say that. However, I believe for the highway salt situation we looked at, the kind of confirmation that you get, gives some confidence in predictions you can extract now. In other situations where you don't have the information, it's highly speculative. That's what you'd have to say for it. You still need the information to confirm the structure that's involved and it has to be the proper kind of average information. To just take one well and try to use that to characterize the behavior of this model, you're doing the wrong thing.

Lawrence Peters: I'm concerned with highway deicing extensively up north and I was wondering if you could show me what your model can do? I mean, I'm using it particularly in very small cases. It's definitely not a regional basis. Could I use your model?

Lynn Gelhar: I'd use a different model. Part of that work that we did for that study was a local, or what we call the local model—just a study convection of the individual well. You just have to make the proper judgment if you're interested in the effect of the individual well. You can use that approach. We haven't perfected that in every detail as yet, but I think John is working on it.

John Wilson: Yes. We're trying to avoid a very complicated model that I was referring to earlier. We're looking at local problems; this is what these numerical models will do, by developing some very simple analytical models that can be applied by your hydrogeologist to analyze the problems of a local nature.

Unknown Speaker: In our section, we don't have the expertise or the manpower to put to this particular kind of approach. If it could be somehow simplified and given to us as a method or a procedure rather than having to sit down and do something original on each case.

John Wilson: Curiously enough, I have a master's student who started to work for me for his thesis which will be completed in June. He just started yesterday. He is going to write a user's manual of very simple models that can be used here in the United States for normal impact assessments and for analyzing ground-water contamination problems in relatively simple geometry. So, yes, we have made the effort in that direction.

Dick Pearl: I want to ask Wayne Pettyjohn a question in light of his talk this afternoon on strip mining. There's a lot of thought being given to using old strip mines for waste disposal sites. What are your feelings on this? Do you think they can be used safely?

Wayne Pettyjohn, Ohio State University, Dept. of Geology and Mineralogy, Columbus, Ohio 43210: Well, I think the case history that I cited shows that liquid and semiliquid waste very definitely should not be put in these sites. And on the other hand, I think that they probably could be used for certain types of waste such as solid waste, and perhaps sludges once the site was examined carefully. In this particular example that I used, the site was examined but not that carefully and it was examined only by a consultant to the firm. It seems almost ludicrous that there weren't some State agencies out there protecting their own interest.

But, yes, I do think that in many situations a strip mine can indeed be used safely for storage of certain types of waste.

Bill Weist: You said you shouldn't use it for liquid waste but was it mainly because of that unknown mine head or whatever it was down in the South that polluted the area?

Wayne Pettyjohn: No.

Bill Weist: If it hadn't been that, I didn't notice any sign of pollution going to the west side.

Wayne Pettyjohn: That's right. There weren't any noticeable contaminants moving to the west but I think there was a slight dip to the east and had the proven underground workings not been there, and had the one that I assume is there, not been there, there still would have been a problem only not as significant. But because there were significant springs issuing from the joints and seepage all around, it was a bad scene to start with. But it didn't get really bad until the southern part was open.

John Wilson: Do you think associated with strip mining that there's a feeling that one has already destroyed the land, so that now it is okay to use it for storage of industrial sludges and other industrial uses which one would not have otherwise contemplated for that particular geographic area?

Wayne Pettyjohn: I think that's true at least in Ohio, under the lands that were stripped prior to some legislation developed in 1972. All you have to do is examine the land and you can see very readily that it can't be used for much. It does have a certain beauty of its own, though. In fact, we drive 1500 miles to come out to the Badlands of South Dakota and see the same type of topography we have in the strip mines back there. There is a little difference, though, the pH of the water is a little better in the South Dakota Badlands than it is here. So I think that is very true. People visualize this is land that has no value at all. It is creating a problem, so let's use it for something, we'll put various goodies in it.

Unknown Speaker: One of your conclusions was that the strip mining pits wouldn't be a good place to put the kind of waste they contained so people couldn't live there. Where would be a good place to put that sort of stuff?

You stated that there are certain types of waste that you know might be put in those types of strip mine areas. What would you have in mind?

Wayne Pettyjohn: Right now, as far as the pickle liquors themselves are concerned, there has been quite a lot of technology developed recently to renovate this material. And that's darn well what they should do, and I think they will, with time.

Another possibility would be to use deep well disposal which they are doing. Now the types of waste that could go into these wells, I would visualize as a waste which does not contain substances that are readily soluble. I really can't go much further than that. It's going to leak out as the stuff is as permeable as anything can be. If the substance is highly water soluble, then it will create a problem but in many of the mines that's already a bad problem because the water discharging is highly mineralized. Perhaps you could think a little differently and put in wastes like a caustic soda or something like that, which then would bring up the pH and maybe then the heavy metals wouldn't be moving with the acid mine drainage. But that's really way beyond me. I really shouldn't be commenting on that.

Bill Weist: In commenting on your question initially, Dick, in reply to using solid waste, I might just mention that the City of Terre Haute, Indiana, is utilizing a strip mine for solid waste disposal. To my knowledge there's no study made yet to determine whether there's any pollution occurring. It's been in operation for several years and there's no complaints and no evidence that it's not working successfully.

Dick Pearl: Are there any requirements in Indiana that the site be evaluated by a geologist and a report turned into the State for their evaluation?

Bill Weist: I believe they're starting to do that now, but in the past there has not been.

G. Lewis Meyer, U.S. EPA, Washington, D.C.: Would the potential for leakage really be so noticeable if you had not put the waste in there? Did the waste, by putting it in there, serve as a sort of collection gallery for infiltrating water and then, was much water moving in the natural state through that strip mine area?

Wayne Pettyjohn: Well, I'm certain that there was some discharge of highly mineralized waters to start with. That was one reason I collected samples on the east side of that one tributary. Remember that one sample I pointed out—site 15—was highly mineralized. I'm certain that before any of the neutralized liquors were put in there that there was a similar type of discharge.

The sludge consists of 70 to 80% moisture and all that is squeezed out and also there is a lot of infiltration when precipitation is about 38 inches a year there. So there's a lot of infiltration of the soil surrounding that pit. Putting the sludge in there created a problem that was different from the problem that existed before and resulted in a great discharge.

Jack Keeley, EPA, Kerr Research Center, Ada, Oklahoma 79824: I have a feeling that most of the work we do in ground water is utter nonsense. For example, the use of BOD in ground water is utter nonsense. Is anyone here doing work on really new technology? Is anyone here doing work on ATP to give an indication of gross biological activity? Is anyone doing work on stable isotope ratios to identify the sources the Connecticut way? Is anyone doing work on organics and their degradation products? You know, we can talk about pH and nitrates for years and years and years. Is anyone really beginning any new technology?

John Wilson: Yes, but there are different levels of technology and it moves from the basic research stage through the applied research stage toward development and finally application. It would have to be appropriate to talk about new technology which is in idea or basic research stage or early in the applied research stage. And we could discuss to the moment the research we all have done in transports of chemicals in the saturated zone but it's in the area of basic research, perhaps much too sophisticated to convey at a meeting like this in a meaningful way.

Unknown Speaker: All the things you mentioned, Jack, are in the area of water chemistry or in the area of disposal of liquid waste. They all obviously bear directly on the big menace to ground water, but I think the average ground-water geologist and ground-water hydrologist when he thinks of new technology, isn't geared up to focus on these water chemistry problems.

Jack Keeley: I agree totally and that's my point. Geologists are rock people. What are you, Dave?

Unknown Speaker: I'm a hydrologist.

Jack Keeley: My point here is that we in the ground-water industry are decades behind our counterparts in surface water. And I don't really see that we're progressing. We're making the same mistakes that they made 20 years ago. And I don't think we have time to do that. What I'm suggesting here is an interdisciplinary approach to ground water which does include of all things geologists and hydrogeologists, but we need to get some organic chemists, some physical chemists, some microbiologists, some biochemists to really develop brand new technology. Now I agree that a lot of this is very basic. We're doing some ATP work at Ada, Oklahoma, and it's, I think, not going very well, because it's very difficult. But wouldn't it be wonderful if we could get one analysis that could replace E. coli?

Lynn Gelhar: There is a need to see this kind of work supported and we have to look to where this kind of work is going to be supported when it's oriented toward ground-water studies. I think that is a serious impediment to this kind of thing. The current federal situation is not one that encourages emphasis on ground water. Isn't that right?

Dick Pearl: You've got a log of good ideas there, Jack. But still the stuff you have proposed is very expensive to run.

Jack Keeley: I maintain that pH was very difficult 50 years ago. What I'm suggesting here is that we start and in one day 18 people have a meter that we stick in like a pH thing, we stick in and say behold. But we've got to start now rather than fool around with BOD's and pH's.

Dick Pearl: I agree with you on that. It takes time and you can't do it immediately, but it is becoming more popular to run it now.

G. Lewis Meyer: The problem we run into, I don't think we're using some of the common tools we have very well even today. I think we need to do some basic things well first.

Unknown Speaker: I'd like to dwell on that a little. We're talking here about new technology and I think when the average geologist and hydrologist thinks today of new technology to aid us in preventing ground-water pollution, we are thinking of more basic things. This morning we're thinking about better septic tanks or better waste disposal systems—ways of preventing gasoline spills, ways of deicing roads without using a lot of sodium chloride, ways of disposing of a variety of industrial toxic wastes that would not involve surface- or ground-water pollution. That is what I think most of us think of new technology. You, Jack, are primarily concerned with new technology of monitoring the overwhelming number of new chemicals that are being injected into the system each year which is certainly a facet of it, but it is almost beyond the mundane problems that are still facing us everyday unsolved.

Wayne Pettyjohn: While I agree with several things that have been said, I'll disagree with you. The point is that we have pH meters or conductivity meters that make several analyses very inexpensively. The thing that's bothered me for years and I shudder to think what would happen if we had new instrumentation, is the fact that you can look at literally thousands of reports and in these reports you will notice some tables with water quality data and in the text it will say that water quality data is shown in Table 3. That's the end of it. That's the end of the water quality discussion. And no one seems to realize that every line on that table costs at least $50. So that all of us, I think, tend to fall down on the interpretation of the data that we have that's readily available. Why develop new types of instruments, which obviously we can't do, to tell us what else is in the water, when we really won't pay much attention to it anyway?

Unknown Speaker: I think one of the problems that I've run into, and I don't have any great training with water quality, is knowing what to measure. Would anybody like to comment on that?

Dick Pearl: You've got a very big problem there. There are new standards coming out for drinking water. We're beginning to recognize now that there are more and more trace elements that we should be analyzing for. The effects that they are having on the health and well-being of mankind and animals as well—it's becoming a very big problem. What do you analyze for? How far should you go with it?

Bill Weist: It depends on the purpose of your study. Maybe 3 or 4 things could tell you if the water's bad. If you knew everything that's in it, then you've got a monumental task.

Dick Pearl: It's the trace elements that you need to know, what's in there, what effect it's going to have on the drinking water of the people in the metropolitan region.

Bill Weist: That's true. Somewhere else you may not have to worry about trace elements. You wouldn't want to analyze it. I don't think you have a blanket answer to help him. There's no set things you should analyze for. It depends on your situation.

Wayne Pettyjohn: I think that the last remark was correct. We could really not say that you should look for these elements or these substances because those that might be significant depend on the type of waste you're looking at. The thing that's been done so much in the past and will probably be done for the next 150 years, is to run a standard analysis which may tell you absolutely nothing, particularly in reference to the heavy metals. We don't know what the significance of these things are. We may not know where they come from. So, without a complete analysis you don't know what to look for. You have to be guided a little bit by the type of waste you think is involved and then go from there.

Unknown Speaker: I agree, but if you go out in the field and you're faced with the products of the pollution and you may have a number of sources or possible sources of pollution surrounding that. So by that you've got to analyze for all possible sources.

Wayne Pettyjohn: Well, in some respects, yes. Even though there may be 20 different sources, you probably have some that are common to all of them.

Unknown Speaker: Then you still have the unknown of the geologist too.

Jan Turk, University of Texas, Dept. of Geological Science, Austin, Texas 78712: I think that one of the problems when we work with some of these lesser known contaminants, such as the trace metals, is our tremendous lack of background data. A lot of so-called pollution cases have been identified without sampling the surrounding areas to determine what the natural background is, you cannot absolutely point a finger and say that contamination has occurred or who is contaminating.

Jack Keeley: I want to agree with Jan Turk. And this was my point a moment ago. Here we keep fooling around with what happens to nitrates, the calcium, and the phosphates and these things in the subsurface when in fact we have not described the subsurface environment as a receptor of pollution. My suggestion awhile ago was instead of measuring E. coli, wouldn't it be nicer to have one parameter which we would have some indication of the gross biological activity which exists in the subsurface? Would it not be nicer to be able to measure the oxidation reduction potential at 50 feet and have an idea of the state of the metals rather than run all these things that may or may not do us any good?

Norman Lovejoy, Nelson, Haley, Patterson and Quirk, Inc., 102 N. Cascade, Suite 202, Colorado Springs, Colorado 80902: I'd like to pursue this because isn't one of the principal new uses of underground water the storage of recycled water for later use and if so, isn't it necessary to really begin to look at the parameters that should be used to measure the quality of water that's being put in there for storage for later use, and what the effect is as it sits there over a period of time rather than flowing down through a stream with all the oxygen? I came late and I'm not very expert in the subject so I may have asked a dumb question. I'm concerned about the use of the underground aquifer for storage for later use of winter waters and recycled waters. What standards have been established for those flows?

Unknown Speaker: Depending on how good a job you do, you can have a very good container. For example, I think the biggest work has been done by the Chicago Sanitary District. They, in cooperation with the Illinois Survey and a number of consulting firms, have done extensive new geotechnical surveys and have located very good places to store water. Before the extensive work was done, they came up with some preliminary ideas of where to store it, which would have been at shallower depths and would have been cheaper. However, later they found that they were criss-crossed by joints.

Norman Lovejoy: Did they have any standards for the water that was being placed in there, surface water or the recycled water? Do they know the impacts of that water on the chemical and physical model of the underground–

Unknown Speaker: The water that they're storing there is storm water and runoff. So it's water whenever they have high flows and their sanitary sewage can't handle it and then it's all pumped down to these storage chambers. Later on it's pumped back up to the surface for treatment. As far as I know, I may be wrong, this is probably the largest scale operation that deals with subsurface storage.

Dick Pearl: As I understand it though, that's not being put into the ground water, it's into a dry chamber.

Unknown Speaker: Right.

Raphael Kazmann, Dept. of Civil Engineering, Louisiana State University, Baton Rouge, Louisiana: We've been looking into this matter of storing fresh water that might have salt water in it and we've also been looking into the changes that surface water undergoes when it goes into an aquifer. We have found that although the water may be somewhat hard when it gets into the aquifer, we can trace the movement of the water in the aquifer. Now when it comes to storage of fresh waters mixed with the elements of the Mississippi, we get out soft water.

Dick Pearl: Warren Wood of the USGS is involved in the High Plains recharge study at Lubbock, Texas, and they have some problems.

Warren Wood, U.S.G.S., Lubbock, Texas 79413: Well, we have done a bit of modeling. In answer to your geochemical questions, we're in the process. We have a digital model now of simple things like solution, precipitation, and ion exchange. It's rather a straightforward model. We can predict fairly readily what will occur, provided we're given some initial boundary conditions as to the water and the ion exchange capacity of the material. Given these we can predict fairly accurately, at least in the situations in the High Plains, what we anticipated at any given time and the depth in one dimension.

Unknown Speaker: Is there a way that a district or agency that owns water can determine the quality the water must be in order to be acceptable for recharge into a particular aquifer? Are there standards by which the engineer can determine the quality that the return flow must be to be recharged and be acceptable from a chemical and biological point of view?

Warren Wood: Given again the basic parameters, you also need the interstitial water which is a part of the site selection criteria that we're developing for recharge. Tell me what your water quality is you want to recharge. Give me something about the geologic section, I then should be able to tell you what that water will look like at various points in time and space and what it will look like 6 months from now when you repump it.

Unknown Speaker: Is biological an important factor in this recharge storage?

Warren Wood: It's important in terms of plugging of the recharge facility, be it a basin or a well. It may or may not be important in terms of the water quality depending on the use you're going to put this water to and the aquifer.

James McNabb, U.S. EPA, Robert S. Kerr Environmental Lab, P.O. Box 1198, Ada, Oklahoma 74820: I don't want to steal my thunder for tomorrow because I'm supposed to speak about biological activity in subsurface systems. If I answer his question too much, I won't have anything to say tomorrow! In my opinion he's correct when he said it may or may not be important.

Unknown Speaker: I'd like to point out that a system making use of all this water is a very adaptive and a very hardy one. You don't have to get down to the gnat's eye to make it go, as far as human beings are concerned. You can take a wide range of fluids and make good use out of it. The only thing that we've got to really watch is the poisons of one sort or another, the metals, complex carbons, or chlorinated hydrocarbons. So that actually it isn't quite as bad as everybody seems to think. Within fairly rough limits we can use almost any kind of water we can store as long as it isn't poisonous. You can go too far in finding everything out in a gnat's eye; by the time you find everything, you've got nothing left.

Dick Pearl: If I may ask a question of Ed Gutentag.

Bob Prill had a recharge study there at Garden City, Kansas about 10 years ago, which never got published. If you can remember, did he have any problems involved in the recharge?

Ed Gutentag, U.S. Geological Survey, Garden City, Kansas 67846: Bob used that pond. The only time he had a problem was the time he used Roderman Dye and he wanted to trace it down. The dye was absorbed in the upper materials of the soil and they couldn't even pick it up using a soil slurry. Jav Gillespie is working on a similar project now in western Kansas. He's had fairly good results.

Dick Pearl: We've pretty well talked this subject to death. Does anyone want to change the subject?

Jay Lehr, Executive Director, NWWA, 88 E. Broad St., Columbus, Ohio 43215: I'd like to ask Ray Kazmann a little more about his miniature model system. You have field-use determined that one can very successfully dispose of waste under certain conditions that essentially will not be needed for potable water supplies. One of the conclusions I drew from your talk dealt very heavily with this density concept. What are you saying to people with waste they want to dispose of which is not as dense as water? Should they utilize an additive to make it denser so that it can be disposed of?

Raphael Kazmann: Absolutely. Use a weighting agent, anything to make it denser because that gives you a factor of safety. Admittedly it's expensive, but on the other hand, these are the ultimate wastes, the wastes that are just impractical. You can't burn them, you can't do anything with them, you can't even contain them on the surface. So under those circumstances the added cost to weight the wastes so they'll sink to the bottom of your receiving aquifer, I think, is not an important parameter.

Jay Lehr: You opened your talk by saying that there were probably too many articles on well technology for waste disposal. Yet, we've had so many failures in industrial wells that were thought to be perfectly good that failed in the sense that pollutants started coming up around the outside of the casing. The pollutants also were found in higher zones than they were initially put into. This would leave me to feel that we have not frequently constructed the wells as well as they could have been to produce these kind of less than perfect results. One of the innovators in the area was U.S. Steel in Gary, Indiana and yet they started having troubles. It seems to me that industries that thought this kind of waste disposal was going to be a real panacea for getting rid of some of their real problem wastes, are putting less emphasis on it now because of problems coming back at them years later.

Raphael Kazmann: You have to differentiate between 2 basic types of errors, the retrievable type and the irretrievable type. For my money, if a man puts a well in and it goes bad, he hasn't lost. All he does is plug the well and drill another one. On the other hand, if he puts a waste in and it gets away, this is irretrievable. What I'm trying to do is avoid the irretrievable errors as I feel technology is in pretty fair shape as far as the actual equipment is concerned and nobody should put a single waste disposal well down. I think it's almost an essential part of a project that there be 2 wells, so that when one is shut down the other can operate. And wells will have to be shut down. Water wells have to be shut down. There is no reasonable length that a waste disposal well will not have to be shut down, treated, cleaned or maybe even abandoned. But this is part of the price of handling intractable wastes. If you're going after 10,000 years of storage, essentially permanent storage, you have to be prepared, and it's got to be done right and it's got to be done thoroughly. It's not a matter of saying $100,000. We're talking now in the $1,000,000 class and we're not going to use this for trivial stuff. Burn it first. Do anything but deep well disposal. But the stuff that you can't handle any other way, that goes down the well.

Arthur Chapman: The concept of the denser the better, keeps the mandate that you can dispose of this waste, whoever does it by reducing the volume and concentrating it. Is that what you're saying?

Raphael Kazmann: You can do it that way too. You need as little as .02 gram per cc difference. The more you can get the better. We've been running experiments anywhere from .01 gram per cc, up to about .45.

Sam Owens, Subsurface Disposal Corp., Suite 646, 5555 W. Loop So., Bellaire, Texas 77401: I think we should clarify one thing. Your model is made on an open hole completion which is really not realistic with what is actually used in an industrial waste application. I would have to disagree with you on assuming that all waste should be of a heavier gravity than water. That assumption would only be true if there is nothing below that aquifer that is going to be of value sometime in the future. In many cases, wastes are disposed of which are of a lighter gravity and they are done so because there is no chance of that waste moving upward into a usable zone. Also you might consider sometime those areas where waste is pumped into a close aquifer which has been pumped out previously.

Raphael Kazmann: You're absolutely right as far as there being a lot of good situations, but these are all field situations and you have to have some principals to go by. In principal I would feel safer when the waste is heavier than the brine or whatever the receiving formation is, because then it goes down. There are geochemical reactions that haven't been looked into. This is purely a hydrodynamic look at a new complicated situation.

Unknown Speaker: I don't want to repute something. What I want to do is clarify again. Yes, in many cases you could add a brine, but in some cases you could not because of the incompatibility with the disposal fluids. But there are other things that could be done to the material to weight it if that's what you want to do. In some cases a disposal well may not be completely compatible with the water. In such a case it was usually common practice to add a fluid as a buffer, to build in a buffer zone.

Unknown Speaker: About Ray's 2-well concept, I don't think this should be passed by so insignificantly. I know of numerous waste disposal situations whereby an agency or even private citizens have indicated the apparent problems stemming from these waste disposal wells and the company involved will fight, argue at great lengths before admitting that there is a problem and maybe eventually get shut down or make some repairs. Had there been an alternate potential of another well, they might not have had to cover up or put up the big fight. It seems like such a simple and a clever idea. Of course, it's used by many water-supply people who recognize that wells have to be serviced all the time. They have extra wells and have to shut down when another needs service. I'm wondering if there exists a regulation in any State that comes close to this concept, that if you're going to have a waste disposal well, drill 2 so that you can shut one down in case something goes wrong or for general maintenance work. Does anyone know?

James Pool, Florida Dept. of Natural Resources, 115 Bloxham St., Tallahassee, Florida 32304: Right now the Department of Natural Resources in Florida has a policy that an experimental test well will be drilled for any injection site. And then that well will require at least one monitoring well separate from the injection well. At any site there has to be at least 2 wells.

Dick Pearl: We just had a deep well disposal proposal presented here in Colorado for toxic wastes coming from the Rocky Mountain Arsenal. It was a 2-well disposal system. There were also stipulations required for back-up emergency plans. If something happened and they couldn't handle it at the disposal site, they had to be able to take care of the waste elsewhere. So we do have that requirement here in Colorado too.

Jan Turk: Professor Kazmann, what's wrong with a fractured formation if you want to inject?

Raphael Kazmann: You'd have to fracture a sandstone formation to inject it. Where do you find some other place to keep the waste?

Jan Turk: I agree, but I think that to clarify the fact that just because you fractured the sand does not necessarily mean that you fractured the shales.

Dick Pearl: Technologically you could probably fracture and inject into it. Politically, I don't think you could sell it to the environmentalists or to the State authorities who've got to approve it.

Unknown Speaker: I think I agree with Ray that you've got to at least not go above the fracture pressures if this is possible.

Dick Pearl: Well, if no one else wants to change the subject, I do. Bill, do you have any idea how much water pollution is occurring from just normal fertilizing of our lawns? Let me give you a little history. People in Denver take great pride in their nice green lawns. And they go to great expense to fertilize, water, and take care of them. You people from the East just can't believe the care that goes into our lawns. The family that won the best lawn contest in Denver just lives up the street from me. This fellow says that he fertilizes his lawn once a month and he cuts it twice a week. What I'm getting at is that he's putting a tremendous amount of 15% nitrogen fertilizer along with all the other elements on his lawn. I doubt if the plants and grass is taking up all this fertilizer and it must be running off. Do you have any idea of the magnitude of this and how much water pollution is occurring from this?

Bill Walker, Illinois State Water Survey, Urbana, Illinois 61801: To my knowledge, no work, at least in Illinois or the Midwest, has been done along this line. I do know that the nitrates are taken up by the grass if you don't put too much water on. Knowing how expensive water is, I daresay that most people do not overwater lawns. So I would suspect that once research is done on this, Dick, I think you're right, that much of this nitrogen is retained up in the upper zone, in the root zone of the plants. I think also that you'll find that this nitrogen, if you don't take the grass clippings off, will just remain in place. However, most people do clean up their lawns beautifully and take the grass clippings away which seems kind of foolish really unless they've made a compost pile out of it. Because they are losing all that potential nitrogen that way. But to my knowledge, there's no research of this one thing. I don't think, however, that it would be very significant on a large area basis on yards, but I do think the farm fertilizer use and misuse might well be very significant.

Ed Gutentag: I've been using 33 1/3. We're in an area with 18 inches annual precipitation and when you fertilize, if you don't get any water on, that's going to burn. So the point is that you have to put enough water on when you do fertilize. You can't put on too much or it burns the grass. So if your neighbor had a nice clean lawn that meant that he got that fertilizer on, he got the water on it, he got it into the roots and didn't burn the grass.

John Fryberger, Engineering Enterprises Inc., Norman, Oklahoma 73069: I have the impression, reading research on the question of nitrate being leaked down from agricultural applications, that there have been numerous cases where they have found an increase in the nitrate in ground water. When they studied this quite thoroughly they found that the increase in nitrate doesn't come from the fertilizer but comes from natural nitrates that were in the capillary zone or the unsaturated zone that were leached down by the application of irrigation water. The nitrates themselves didn't come down from the fertilizer, but were leached out of the soil.

Bill Walker: We did a detailed study in southern Illinois along this line and at the end of the growing season, we took core samples in the upper 18 inches of the soil throughout a man's farm. We found that man had at the end of the growing season 186 pounds of nitrates per acre in that upper 18 inches. This was after he had grown 100 bushels to the acre corn on that land. Then in the winter, during the time when these applications should be minimal, practically zero, we went out again after the fall rains had taken place. We found that all the nitrates that were in the upper 18 inches at the end of the growing season in late fall, had been washed down to the ground-water reservoir. So, when we go this route and try to blame it on organic nitrogen down deep that somehow mysteriously without oxygen converted to inorganic nitrate form and then went on down or did something.

Jan Turk: I'd like to ask, was that natural or organic nitrate?

Bill Walker: This particular case had 6 sources of nitrate, nitrogen on the farm. They had an old privy, septic tank, an abandoned chicken yard, an old horse barn, an old cow barn, and a hog lot.

Jan Turk: I'm still not sure that answers the question. He was talking about the 186 pounds of nitrate.

Bill Walker: This was all due to farm fertilizer and another thing that this was due to was nitrification of the old corn stalks plowed back under. And we've been ignoring this in the past. We've been ignoring the fact that most of the uptake of nitrogen in plants is not going out in the seed; instead it's being returned to the land and plowed down and maybe this takes 3 or 4 years to totally nitrify by bacterial action in the soil. This I think will live to haunt people that use spray irrigation of sewage disposal.

Jan Turk: You do have very good data to indicate that in some areas and various regions that natural soil nitrate can be quite excessive. In fact, we studied an entire county and in those areas we have in excess of 1000 pounds per acre of nitrate within a very shallow zone and there has never been any fertilizer added.

Unknown Speaker: Was this actually the nitrate form or was this a total of nitrogen determination?

Jan Turk: This was in the nitrate form. We're running higher in some cases, 400 mg/kg.

Unknown Speaker: Very little of this goes to the ground-water reservoir? So this is a storing or banking of this nitrate in this upper zone just due to evaporation taking it back up—so this could be 5000 years of accumulation in that area?

Unknown Speaker: Probably not, but it could be.

Unknown Speaker: In our prairie soils we have some areas with 10 feet of prairie soils, it's just in organic form. It can't convert. But once oxygen or bacteria can get to it, then it does.

Unknown Speaker: Right. Then it's converted over to nitrate form. But as long as it's still in the prairie condition an awful lot of it can remain in the organic form.

Unknown Speaker: But that is not a breach of plants anyway. The only thing the plants can use is nitrate. In most of the crops they have to use it in nitrate form. So if it's in some organic nitrogen form, it stays there. They can use it and water does not dissolve it so there's no reason why it wouldn't stay there. We used infrared on our hazardous chemical study this summer and fall in Illinois, hopeful that the infrared would give us a finger point at least of which way these pollutants might be moving from the stored sites. Now we know that we can't get a complete definition of a blob or whatever moving out because much of it will go down below and go through underneath the reach of the roots of the plants. But we hope that enough of it up in the capillary zone will have been absorbed to actually give us an arrowhead point of which way to test for these movements. This is starting to be used in other parts of the country too. This might be something to think about for your study.

When I first mentioned this to the Kellogg Center in Michigan 2 years ago, they didn't think about that as being a method. Now I guess Cornell and somebody else is beginning to use it before I could get somebody to use mine.

John Osgood, Pennsylvania Dept. of Environmental Resources, P.O. Box 2063, Harrisburg, Pennsylvania 17120: There are a few points that I would like to make. One is the volume of hydrocarbons lost is not as significant as the hydrogeologic system which they are deposited into. A lot of people at EPA I know take great pride in being able to identify the volume of hydrocarbons lost and that might be significant in surface waters because there's rapid dispersion. In ground water I'd be able to say X amount of gallons were lost this year is not as significant as the number of cases or the kinds of problems that develop from those cases. We've had situations where as much as 10 gallons were lost for a 2-day period and it knocked out 3 wells for a good 2 months. In other cases we've had situations where 30,000 gallons were lost, recovered, and there was no problem. Containment right at the site and recovery within a matter of days or contained at the site for long periods of time while the renovation of the ground water continues, I think we have to be concerned with that when we set up statistics.

We in Pennsylvania found that we had a little difficulty at first selling the idea that there was in fact a problem from hydrocarbon spills. The feeling was from our surface-water people that the surface water was where the problem was in hydrocarbon spills. We developed some information by indicating that we had a feeling that there were a lot of problems. That didn't sell. So what we needed to do is to develop statistics of ground-water problems related to hydrocarbon spills so we can support some of the legislation that's needed. You can't say well we've got 20 cases here that caused a problem. You have to have statistical support that you had a major problem and that, of course, goes without saying.

But it seems to be especially difficult with governments and seems to be even more difficult when you're working with ground water because we have the same old thing that everyone of us faces, that it's out of sight, out of mind. The people who should know the most about the damage that can be caused know the least, care the least and unless they're really pushed, you can't get anything out of these people. So we've got a real tough selling job ahead of us. We have been successful in Pennsylvania. I think a few other States have been, but this is something that is ahead of us in this area of legislation.

Unknown Speaker: What recourses are available now to the State to levy fines?

John Osgood: I can only discuss Pennsylvania because I'm most familiar with that. We have the Clean Streams Law and one particular provision of that has to do with any spills that get down to the ground water. Now if a spill occurs the person who is responsible for that spill is obligated to immediately notify DER. The majority of our cases have not come that way; they come from problems that have developed from the spills. But nonetheless they are obligated according to our law to notify us. If we get a notification and respond, then they have 15 days in which to recover to our satisfaction all of the pollutant that got into the ground water. After 15 days, they can be fined up to $1,000 a day, plus additional fines can be levied. We have an enforcement officer in each region who issues enforcement orders. We have a staff of attorney generals that support us. We can take them to court and fine them and we have. And in our State at any rate, we are getting to the point where people take us seriously. I think we have generally some pretty tight regulations which permit us a great deal of levity in the way we approach a problem. You need specific regulations, however, and that's what we're working on.

Unknown Speaker: Do you have a percentage figure of the percentage of instances that have resulted in fines that have been assessed against the violators?

John Osgood: I really hate to get into this because our attorney generals feel that these are rather minor problems compared to some of the rather tremendous ones they have. So we can go up to a certain point. We usually get our own way through persuasion. I think it's fairly easy because the repercussions of the spill are so great. We had a service station 2 or 3 months ago that had a leak in their tank and we were informed. So we went out, recognized that they had lost some gasoline, and called up their district headquarters, which was for the entire northeastern United States. They thought nothing of it—so what, they lost a little bit of gasoline! We informed them that we had some explosions; we had several major problems connected with these spills. They had absolutely no idea that it could possibly happen. So they sent out some people to take care of it. They didn't take care of it properly. Within a month there were about 6 homes who had lost the use of their wells. They are still out and it has now been 3 months. It's highly unlikely that they'll be able to use their wells for another 6 months anyway. And that station, that company is responsible to every one of those people. They all have private suits on them. The State has suits that they have to clean it up. They have to continuously monitor it. The station is closed. That's another neat thing. There is no way they can get back in business until all that contaminated earth is removed and depending upon their cooperation you can have them remove a square mile of soil if you really want to push the law. You can inform them of that capability. They see dollar signs and they'd much rather put in monitoring wells or trenches or hire consultants or whatever.

Jan Turk: It seems to me that your discussion was oriented entirely on detecting and how to clean up spills. As I recall your slides today, in excess of 50% of the cases were related to individual service stations. Is that correct?

John Osgood: Yes, that's correct.

Jan Turk: What has your group done in terms of setting criteria for installing these things? It seems to me that if you could set the regulations for installation of the storage tanks at individual service stations you would immediately eliminate 50% of the problems. In other words, you can make a subsurface tank which is a fail-safe system that cannot possibly leak, whether it is a tank within a tank or a tank in a vault or what have you, which would immediately eliminate 50% of your problem. I hope that wouldn't reduce the staff from 16 to 8, however!

John Osgood: I might say that we are working on some regulations with respect to service stations. The vaulting method, encasing the tank in some sort of tank, we've thought of using concrete, however, it does crack. You have transportation over the concrete, over the tank, of heavy vehicles and that would also have a tendency to weaken the particular vaulted system.

We also have a tremendous expense. We have some 11,000 service stations in the State. We have 2300 tanks going in every year, being replaced. We have a lot of activity and a great deal of expense connected with that. And I doubt that politically we could get a concrete-type vault in.

Now something that we have just begun thinking about is another type of environmental isolation. There are some on the market now that have come on very recently. Some materials which when they come in contact with gasoline, or any hydrocarbons, swell. And if you put them in a confined area, when not in contact with a hydrocarbon, they do permit water to go through them. So you don't have a build-up of water within this vault. But when they come into contact with gasoline they immediately swell and seal the entire system closed. And we're kind of thinking of orienting our program towards that. It's economically practical. We have to do a little bit more research, get a little more information. We would like to have some sort of a vaulted system on this level with a monitoring well with an alarm system in there so that the tanks can be removed.

Everybody seems to be thinking fiberglas is the answer. There are some problems with attempting to put fixtures on these tanks; that's where the leaks are occurring with fiberglas tanks. They're fairly new so we haven't gotten into any problems with construction or how they're put in. I imagine they'll be pretty good.

The steel tanks, of course, rust. They're beginning to develop so that they can be competitive with the fiberglas tanks. They're developing coatings for them, both inside and out. So this may also be something we can look forward to.

In Pennsylvania, we're oriented toward back-up systems. The first step is environmental isolation and if that fails, let's get a back-up system that can alert us to the fact and hold it until we can react. That's true for landfills or service stations or tank farms.

Leonard Wood, U.S.G.S., Reston, Virginia 22170: I'm wondering what experience Massachusetts was having with their law that requires all new gasoline tanks to be put into concrete vaults?

Unknown Speaker: I am not familiar with that. I have no idea.

Thomas Canfield, U.S. EPA, 1839–16th St. NW, Washington, D.C. 20460: Could you explain a little bit about landfill isolation, the technology you're using? How many sites do you have that are isolated?

John Osgood: I can't give you an exact figure of the number of sites. I would imagine there'd be around half a dozen in the State that are going this direction. The thing is that we started out the same way, close up all our dumps. We've identified the number of dumps and then tried to get them under permit, the idea being that if they didn't turn out to be environmentally sound facility, they would not get a permit. We put a lot of money and effort into examining natural renovation for these systems. The geologic consultants filled out a ground-water module which was quite extensive, proving to us that there was suitable soil underneath the site so that natural renovation could occur. They designed the facility for people who did not have a very strong background in blueprint reading or map reading or anything else. And when they finally did get their permit, they put the trenches any place they pleased and it forced us to go back in and in some cases require them to remove all the waste from the trench and put it elsewhere. We found that, practically speaking, we couldn't be at every site all the time and that they were not really working. So we are heading towards this more or less environmental isolation where we have kind of 2 approaches. One is, you use a manmade liner with a back-up system, in some cases we have 4 different back-up systems to support this environmental isolation. If one fails then the other one can be used. The other one is controlling the ground-water flow system in such a way as to precipitate a viable type of collection system. In other words, you can use the natural ground-water flow system to transport the leachate to a collection system and then treat that. And of course we need a great deal of monitoring information and a great deal of skill to design the facility in such a way that that will be done. This is more or less the way that we are headed.

Dick Pearl: Do you feel that manmade liners are adequate for environmentally isolating your landfills?

John Osgood: Compared to what? I think –

Dick Pearl: Almost anything.

John Osgood: Better than a clay, yes. We don't use just one system. We will have perhaps a clay with a manmade liner on top of it with a natural collection system under that and natural renovation between the natural collection system and the bottom of your liners, we're rather conservative in our approach. As a result we haven't gotten a great many permitted.

Unknown Speaker: What's happening at the other sites? How many sites are there total?

John Osgood: Totally permitted? I don't know.

Unknown Speaker: How did you determine how much fluid was lost and how do you know when they're efficiently cleaned up?

John Osgood: It's very difficult to know how much is lost, because, for instance, a service station can have a hole in its tank as I indicated and not know if a slow leak over a long period of time can account for a considerable amount of product and it can be dispersed over a large area by the time it is realized. We don't really approach the problem with the intent of finding out the total amount that's lost. We want to try and renovate the environment and recover whatever is there. If we know it's there to begin with, that's all the better because we would keep track of how much we're recovering and relate it to what's lost. Pipelines, for instance, lose tremendous volumes and don't know it. They can lose 15 to 20,000 gallons and not know it with a small leak. And, of course, if they don't know, then we can't know.

I want to say one other thing in the case you mentioned, the Mechanicsburg spill we had in 1970, there are 3 tank farms, 3 storage depots, within a quarter-square mile area and approximately 4 pipelines, I believe. 270,000 gallons of gas, raw gasoline which was fed back into the pipeline, have been recovered. We have not found any person who has lost any product in that area in spite of the fact that we pressure-tested every inch of the pipeline. We checked every line and tank in the area. There is no source for it. We feel we had a source, but couldn't prove it in court, actually out of court. We didn't feel we had a strong enough case. So what we did, we have another little tricky thing in our State law. That is, if you own some property and there's contaminant on it, you are responsible for cleaning it up, whether it's yours or not. So therefore, if a service station has a spill and that spill moves under its next door neighbor's property, we can hold the next door neighbor responsible for cleaning it up. We don't do it, we have it. Now here's where it's neat. Let's take the Mechanicsburg area. We had all these potential sources. The product was under all of them. We felt they were all responsible and we were able to set up a task force of all these abusers. There were some 5 or 6 different companies involved. They pitched in together and set up a task force. They are cleaning it up under this task force. We haven't had to go to court because we have the necessary strength to do it if we want to. We have a government task force as well as a private industry task force. It's rather cumbersome. It took quite awhile, but it's being done. Otherwise we couldn't have done it. The State doesn't have the resources to clean up 270,000 gallons of gasoline.

Bill Walker: I'd like to address my question to his previous discussion there on garbage dumps and making them isolated from the ground-water reservoirs and I know a lot of the literature on the subject has been based on the West where we have very little rainfall. But in the humid regions of the country where you do have quite a lot of rainfall, if we do isolate these things from the ground-water reservoir, we are almost forced then to make the top completely impermeable to keep the rains out. Because if we do not and we do get leachates from these and we say that we're going to collect this stuff and treat it, how are we going to treat it? And so you have leachates that are high in sulphates and all these other little goodies and you say we can't dump it in streams and use the streams for dilution. Well, I would like to ask you how are they going to treat it economically, or any other way really, to remove these leachates?

Unknown Speaker: First of all, you know, there is a principle where you can environmentally isolate these landfills and then put a spray irrigation site on it to stimulate the production, which will stabilize the site much more rapidly.

Bill Walker: Where will the leachates go that you are stabilizing it with?

Unknown Speaker: They'll go into a collection system.

Bill Walker: How can they be treated naturally, economically? Let's be realistic. Do you have a site, first, in the State where you're doing it?

Unknown Speaker: We have several collection impoundments. We have aeration in one. We have lime treatment in another. Polishing impoundment, they usually have 3 of them. And then they go to surface waters.

Bill Walker: And then they dilute.

Unknown Speaker: I think we're fooling ourselves if we think that eventually we'll be able to catch this leachate and treat it. Because if they enforce the surface-water regulations right now, we couldn't do it. And later on it's not going to get any cheaper or easier because they're working toward clean streams all the way back. That was my point in my talk this morning when I said that all of these various ecosystems must absorb and be capable of absorbing by law their fair share of the pollution. And I think that this is a very real point. We're pushing for that and we're not pushing very realistically for it, I think. Eventually it has to be somewhere and in those low concentrations about the only place you can put it is in the surface-water streams. But if everybody does it, then the surface-water streams get degraded too much.

Dick Pearl: Bill, I think we can environmentally isolate a landfill. So when you're in the process of filling it, it's environmentally isolated and when you're finished with it, it's environmentally isolated, and you will not have leachates into it if you do the proper job with final grade and design.

Unknown Speaker: I don't think you can ever say you'll not have leachates in it.

Dick Pearl: Well, it will be a minor amount and they won't get out.

Bill Walker: I don't even think it will be a minor amount. And you can't speak of a minor amount in the West. But I don't think in the East where we get up to 10 inches of rainfall on sand and 2 or 3 inches through the tightest place we've got, that's not a minor amount really. Because if you get 3 inches going through there picking up leachates, that could be very highly concentrated stuff. And if it goes out of there in a blob or a bulb and starts moving through, it doesn't mix with native ground water very much. Now, here again, I say we've got to separate our thinking from west to east.

John Osgood: In Pennsylvania right now, the existing State fire marshal has control over the tanks. Every service station owner must stick their tank in the morning and at night before he opens and after he closes. He has to keep records on it. Now small losses will not show up on this stick because it's a very primitive method of identification. What we are moving toward, what I know other States have already done, is to develop some sort of an annual hydrostatic pressure test. Either annually or some interval where they have to pressure test the tank and keep records on that. These are much more accurate. They may go from one pressure test time to the next, but I don't know that we can do a whole lot more than that practically. I would imagine that we'll concentrate the pressure testing in the earth the first quarter and the last quarter of whatever the tank life is. And that has to be determined since these seem to be more or less the most sensitive periods for a tank. We might go to an annual method. Colorado has done that from what I understand. This is probably the best method that you can go to for prevention. The other is for them to check their records and continue dip sticking every day. And identify whether or not they find water in the tank. If there is a hole in the tank, top of the tank or the side, precipitation is going to add water when it infiltrates through the soil. It's going to add water to the tank itself and then they can identify with their gaining water or they can identify whether they have serious losses or not. I would imagine that would be the best approach. Maybe somebody else has some ideas.

G. Lewis Meyer: I'd like to pursue this secure landfill or the liner thing a little bit further. There are some kinds of waste you cannot treat by spray irrigation. Now you can make impermeable liners and you may succeed in making a bathtub. So if you do this then you must have an impermeable cap or it seems like you should have. Now, does anybody know of any technology available for making impermeable caps? I haven't heard or seen any and it's a real need in the field of hazardous and radioactive waste disposal.

Dick Pearl: Bill, shoot me down very vehemently. The reason I say this is that we've got one project out here on Clear Creek which is an experimental landfill along these same lines, simply a bathtub. They're taking impermeable bedrock and plastering it on the sides about 10 to 12 feet thick. And when they get through they will plaster impermeable clay on the top of this thing. They have peripheral drains all the way around it. They're collecting all the ground-water movement through this area. Of course, we don't have the precipitation here that you have back east, we're only looking at 16 inches here in the Denver metro region.

G. Lewis Meyer: The normal life cycle of a garbage dump or a landfill is that within the first 5 years or so the waste begins to compact and caps normally start collapsing, cracking. And this process goes on for as much as 30 years. So how will this sort of a landfill hold up under this sort of situation?

Dick Pearl: I think time will tell. I really don't know. It's a sanitary landfill in the truest sense of the word. Each fill is a cell unto itself. They are covering and compacting each fill cell on all sides. They have a sheep's foot roller in there to compact it.

Unknown Speaker: Is this clay or just native materials they took out from somewhere else?

Dick Pearl: It's the Denver shale and siltstones. I don't remember what the permeability rates are. It's almost zilch.

John Osgood: I think the point is that with this type of a system you can control leachate production. You can hold it to a very low level or you can stimulate it to a very high level. And by perhaps surface-water diversion, some sort of an interception system, you can control the rate at which it's produced and yet not do any harmful damage.

The thing I'm concerned with is that people consistently try to take a waste and inject it into the ground or put it into the ground in some way, with only limited control on it down in that environment. We could do the same kind of job on the surface of the ground if nothing more than taking the ground water out of the ground, putting it into a large impoundment of this stuff, diluting it on the surface and then putting it on the ground. It would be more expensive, of course, but it wouldn't be astronomically so, unless you're dealing with huge volumes of water which might be the case in some situations. But if it is, then you shouldn't be putting it into the ground anyway.

I personally favor a more controlled environment where you can treat the stuff and then put it down into the ground if you want to when it reaches a certain level. That brings us into the next problem, which is probably the most pressing that we have in Pennsylvania, and that is, the question of ground-water quality criteria or standards. And that one we've gone around in circles with everybody in our department, everybody outside of our department, all the surface-water people. What is an acceptable level of control degradation of ground water? Somebody's got to work that out. EPA is beginning to and we are trying to do it also.

Lawrence Peters: I was very interested in your concept of making all the known ecosystems share their weight of out waste flow. Do you have any comments to make about how we would go about this?

Bill Walker: Yes. I have a report that was published in the July-August issue of *Ground Water*, "Monitoring Toxic Chemical Pollution from Land Disposal Sites in Humid Regions," and I would refer you to that. But in this sense, we have in the past at least, just had a few wells not even knowing what depths to put around these things, not even knowing whether they were upgradient or downgradient and usually 4, that's a nice number. So put 4 on a side. We haven't even monitored the plant build-up at all. We haven't monitored overland sheet runoff away from them at all. We don't know how much was taken off in the crops. So I was pointing out in my talk today that we must find these things out because we know not how much each ecosystem should and could absorb. I think the air can take more, in many areas. I think surface water can definitely take more. And I think surface water should take most of the load because we have the perfect measuring indicator out there of it—fish. People laugh about this but they shouldn't. Because we normally can't spend enough money to continuously monitor a stream. But those fish are monitoring it for us completely. So if we keep the native fish alive, or keep the water pure enough to keep the native fish living and then watch it when they start dying, then we can track them upstream and find out what killed them. We can see that. There's no fish underground. So you know, it's hard to tell when ground water's polluted. But at least everybody's expert. Any fisherman is helping us police surface waters. Nobody can help us police ground water, not even ourselves.

Unknown Speaker: With one extreme, you get a fish killed. But on the other extreme, you can get something like sexual malfunction, which is very hard to pick up.

Bill Walker: Here again, I think that we have been looking down a small barrel thinking that we the geologists or we the hydrologists, can solve all the problems. What makes us think that we should not have a fish biologist on our team? And so, in this sense I think these problems are far too complex for us to just look at it from our little viewpoint anymore. And I definitely think the sex life of the fish would be an indicator here. I don't know, because I'm no fish biologist. But I'm sure that if we got together with a team like that and kicked this problem around, it would be awesome to see what kinds of solutions we'd come out with. For instance, you take one single pollutant, then maybe, at least, 2 or 3 ways of getting rid of it into different ecosystems. How do you make the decision on which one is going to bear the load? I can't, but I say that somebody must decide real soon. All I know is that I can see it building up in the soil. I've got enough sense to see that and I can see it in the plants. You know the thing that started this mess was over there in Pennsylvania basically. You know they have been telling us all these years with their data, that there was some buildup in the trees out there of these chemicals. Nobody's even paid any attention to this. They have been publishing their data pointing out that the plants were building up some. It's especially dangerous, and that's one area I didn't even get into today. Read the paper because I did get into these other areas and in this sense I think with the sprayed irrigation of sewage sludge that they're preaching right now, they'd better start monitoring buildup in plants. There's research going on right now in Illinois, for instance, and one of the researchers told me the other day that he is getting some buildup in plants of hazardous chemicals that are unheard of ever before. I said, why don't you publish it? He said, he was afraid to. Now here is the kind of thing we must face openly, and people that want this to succeed are even hiding data, or not necessarily, but they're just kind of covering it up. We must have this data.

John Fryberger: I was going to ask one more question about the gasoline. What conclusions did you come to in using the bugs that were developed to eat the oil and ocean oil spills? Have you found any bugs that would work in the ground water?

Unknown Speaker: We have one case with some 197,000 gallons of high test fuel; it was very, very high test gasoline. The company recovered all but 90,000 gallons immediately. They recovered another 30,000 initially from their pumping program to recover it physically. They used biological activity, biological degradation by pumping oxygen, nitrogen and a phosphate buffer into the limestone area, and this supported a biological community which did break down another 30,000 gallons, it was computed, of product. So it has worked. The unfortunate problem with this is that the report, which was excellent, was not made public. There was no way we could get them to make it public because this particular company did not want the bad publicity from losing all this product. They didn't care about the good publicity from being able to develop this method.

Unknown Speaker: Was a check of nitrates and ammonia made after this study? Because if you put ammonia and nitrogen and all this other stuff in there to help cultivate the bugs, then you regenerate some ammonia and they run in some problems in some parts of the world, by polluting with nitrates instead of fuel oil.

Unknown Speaker: I don't know.

Unknown Speaker: It seems to me that this is a problem we ought to address ourselves more to—solving one problem without creating one that's even worse.

Jerry Hendricks, Sieio Inc. Consulting Engineers, 309 Washington St., Columbus, Indiana 47201: The question is, from the gentleman from Pennsylvania, what standard should be used to evaluate ground water and I would like to answer the question, what's wrong with the Drinking Water Standard?

John Osgood: Many of the parameters used in drinking water are destructive or harmful to aquatic life. As a result of that, for instance, EPA just recently in connection with their spray irrigation, I think they composed some regulations to establish some sort of ground-water criteria connected with it and used Drinking Water Standards. In doing so, they violated the water quality standards for surface water. I don't think we can just walk in and say that we'll permit degradation up to Drinking Water Standards. I don't think it will go. That's one of the problems. What is acceptable? What concept do we use when we talk about water quality standards? Do we talk about maintaining natural quality? Do we talk about maintaining drinking water standards? Because that's what man uses it for? It's not the only use of ground water by any means.

Unknown Speaker: I don't say let's pollute the air and surface water any more than necessary. But I do say that hydrochlorine and hydrocarbons can be burned easier. Along this same line, you can scrub this stuff and end up with a residual that you can do something with. By the same token, fuel oils and some of these other things, the waste oil can be done the same way. By now, when you say that the fish life out there might be hurt, which would hurt somebody raising oysters, for instance, that's good. However, by putting it underground outside, you say it isolates it from the system. Basically, it does not. Because they're all interconnected. And with the ground water moving to the surface water and surface water moving back and forth, to the plants taking it up as it goes back and forth, we're not really isolating it. We're getting it out where we're hiding it, where it's a lot more dangerous. This is the reason I say, watch the ground-water part.

Unknown Speaker: We talk about sewage treatment systems or we talk about spray irrigation, the Penn State program. They may not have published their data. You talk about putting into a surface-water system, then we've dispersed it for how many miles?

Unknown Speaker: If you concentrate it into plants, then what are you going to do with the plants? Because you can't feed it to the animals, or you can't burn it or you'll ruin the air, or if it stays there and it dies and decays, then that stuff is released to the ground-water reservoir. You see, even in the plants you've got to know how much is there and what you're going to do with it afterwards.

David Johe, Ohio EPA, 361 East Broad St., Columbus, Ohio 43215: This question came up just a little bit ago. Why not use Drinking Water Standards? One argument against that—in our State of Ohio and somebody mentioned in Texas, the natural ground-water quality cannot meet Drinking Water Standards as it is.

Unknown Speaker: So what you're saying is that Drinking Water Standards would be a higher standard than naturally exist?

David Johe: So what I'm saying is that if we enforce the Drinking Water Standards, they couldn't even pump water through the ground because they would have to discharge it later and they couldn't discharge it.

Unknown Speaker: I think this is the first part of this whole thing. Who's working on it? Who's even thinking about it? I haven't yet met anybody looking at all of these things in every perspective yet. I see everyone of us looking at it from a different angle. If you get a bunch together, it's awfully hard to even talk among yourselves. So we've got to do that, but I don't know what vehicle we ride to do it.

G. Lewis Meyer: Maybe this could be one of the useful things that could come out of this bull session—that this is a problem that has been identified. It could be a recommendation that we need to have a working group, a panel, I don't know what mechanism, but some mechanism to make some recommendations on where the loading does go, on how to balance the system out.

John Osgood: I'd like to say something relative to that. In Pennsylvania we have a statewide water quality management plan that was originally budgeted at $10 million and is now pushing $20 million; and over 10 percent of it is going directly to examine the interrelationships between man's activity on the surface of the ground, on the surface of the earth, and ground water and his use of ground water and his activities relative to ground water. We have 5 major ground-water consulting firms who are involved in this. And we have technical meetings periodically where we kick these points around. Plus we have representatives from the State Geological Survey and other areas within the State government who are ground-water geologists or people who are oriented towards ground water. We have talked and we have talked and it's just almost impossible to get one philosophy which is satisfactory to everybody. And then, who gives in? Do you destroy the environment? Do you permit only this much environment? You know, ground water's really the last frontier in waste disposal. We as a State regulatory agency probably have to make the decision. It's our obligation to. But it's a tough thing to face.

Bill Walker: Do you mean that the State has to do it? Because we had that problem in Illinois a few years ago. We tried to make some pretty rigid laws and all at once Indiana started getting them. Along this line it seems to me that the States, even though they like to have State's rights, really shouldn't expect to do it. Because it seems to me that somebody big that's setting policy for all must set this policy. I'm for EPA, in that respect.

John Osgood: The only reason I said it was up to the State is because we've had EPA involved in this. Our federal legislature has not really addressed itself directly to the problem to give EPA the authority to move in. And they have been unable to do that really, so, if they can't and we're under the pressure, we're going to do it.

Bill Walker: Sure, you have to. But it seems to me the better deal would be up much higher though.

John Osgood: I agree. We have Ohio and New Jersey which has received quite a bit of Pennsylvania's waste and they're cutting it off now. And as a result, people are now going to have to spend a little money.

Unknown Speaker: We have a State law, and I think most States do, that says unless you can prove they are polluting, you can't stop them. Now they have been smart enough to buy enough land around here. And you remember that this stuff moves only a few feet per year. So they're safe until they go bankrupt a few years from now or go out of business. And in the meantime the State could not turn them down on the next 40-acre permit, because we couldn't get into the 20 acres to see. They couldn't turn them down because they have complied with every rule.

Unknown Speaker: Don't you have the control over where the monitoring facilities are supposed to go?

Unknown Speaker: You do. And you know what? They put the monitoring facilities in. They had some beautiful experts in there, mind you, before they did this. And these experts are beyond question sort of thing. And they passed through a tight clay down about 40 feet level and put their wells below that. They did not monitor any wells at all.

Unknown Speaker: But don't you have the right to say, monitor this parameter?

Bill Walker: Well, I don't know about your State. You guys got some pretty good ground-water people and ours does too now. But the trouble is many EPA boys on the State level tell me, look Bill, quit trying to get this ground-water protection. We've got enough trouble protecting surface water. And we don't have any people that know ground water. And if we did pass some good ground-water protection laws today, fellows, in your States, what kind of ground-water people do you have that could enforce it?

Let's take this situation where we've got 100 feet of saturation. Now then, we know that a glob of this stuff moves in, it's got a different specific gravity. Now then, it's going to go in some permeable zone. But yet you're going to slop this kite down all the way. Now you've got 100 feet of saturation and you've only got one foot of pollution. And 100 feet of water comes into that hole that has a very low chemical concentration with one foot that has a very high. You get a composite sample. Now where are you going to set your pump? Up at the top? Yes, usually you do and that means you're going to get the fresh water off the top probably. Or maybe you do pump it long enough to pump all the water out, but you've got a mixture of 100 to 1 dilution right off. So when we start trying to monitor all the way up and down the hole, which we usually do, or else we measure just the top. That's usually the best, it's cheaper. We put all our monitor wells shallow, even though this stuff is heavy and it's going to go down to the bottom maybe. So, here's the thing that I think we ought to face real strongly here. What does constitute a good monitoring system?

Unknown Speaker: Bill, why don't you put yourself a pump outside the property line and pump the waste over to it?

Bill Walker: We're planning on doing this sort of thing. We can move within 150 feet of their property. And even though we don't think it's had time to move, we are going to put observation wells in the zone we know it's moved in. And it's on State property and we will monitor.

Charles Kreitler, Bureau of Economic Geology, University of Texas, Austin, Texas 78712: You comment that you'd just as soon have EPA set up some sort of nationwide standards. The people of Texas sure don't want to see that.

Bill Walker: People in Illinois don't either but they have to, I believe.

Charles Kreitler: And I think they're right. The problems in Texas are not the same problems as they are in Illinois or in California.

Unknown Speaker: What problems are not the same? Give me just one problem that's not the same.

Charles Kreitler: Our air pollution problems are not the same. Let's just take an SO_2 coming off the four corners. We have a completely different set of problems out there as they have in New York City.

Unknown Speaker: But you have air pollution. Now they can set certain standards on air pollution with certain percentages or whatever.

Charles Kreitler: Right. If we can develop a flexible system which deals with the problems of Texas in relationship to the climate, the geography and the geology and all this sort of thing, which are applicable to Texas, fine. The standards that are applied to Illinois should not be the same standards applied to Texas.

Lawrence Peters: I'm from Canada so maybe I'm talking a little bit out of turn. I think it would be a good thing to define not only geographic areas but to define beyond State boundaries, and to really get down to the nitty gritty and say, okay, what ecosystems are being disturbed? Use the same boundaries that nature is using.

Bill Walker: I wrote a report last year, "Where Have All the Toxic Chemicals Gone?" And I pointed out at that time that they better soon get a big meeting together with all the States, because at that time we were shipping ours out to somebody else. Now it's come to haunt me because I found out that everybody's coming back. I also pointed out in that report that Canada and Mexico should be in on this conference. Because if they stopped them from doing it in the U.S., pretty soon you guys would be getting it.

Unknown Speaker: I'd like to address that question to the EPA. What would happen if you had such a conference internationally speaking? You couldn't make laws that would pertain to them, but if forced over on them what would happen there?

Unknown Speaker: I'd assume that they'd work on a similar basis as they work out agreements on the Great Lakes and the Colorado River.

Unknown Speaker: It's going to take the goodwill of all parties, and the States surrounding the Ohio River have gotten together. They seem to be doing a good job.

Unknown Speaker: To further amplify Bruce's comments, it's not a water quality problem but a ground-water problem. They are going to have a hard time getting something through the legislatures in the form of a bill which will regulate ground-water pumping in Houston. Because the people in the High Plains are going to object because they feel it's going to regulate them. And if we have these type problems in Texas, what about the whole United States?

Bill Walker: This hazardous chemical thing is so nationwide, and international wide, in scope. We must set priorities first and not worry about nitrates and some of these other spurs. Let's worry about this real hazardous one. And worry about where we can put them, whether the ocean or wherever.

Unknown Speaker: I'm under the impression that an awful lot of work is being done on heavy metals.

Unknown Speaker: I'm not worried about them too much because they don't move too far it seems. I'll know more after I do this study. But some of these others are known to move a lot, so heavy metals should be under something, chlorinated hydrocarbons, for instance, it seems to me.

Unknown Speaker: Just for the record, which hazardous materials are you overly concerned about?

Unknown Speaker: Well, EPA's got about 7 dirty heavy metals, I guess. That's zinc, lead, cadmium, arsenic, nickel, copper, and mercury. Now some of the others are coming into the picture. Those ECB's haven't even been looked at and organophosphates haven't been looked at.

Unknown Speaker: These have been looked at. As for their movement and their attenuation capabilities in various kinds of soils under the various kinds of climatic conditions, not really. In the labs they have, and they're not getting any movement in the labs. We've got 2 sites we're going to study heavy metals on, that have been there for over 100 years. And they have all the dirty sevens in them and we are going to find out. And we suspect that nickel will move further, say, than zinc. We suspect that some of these others will have different attenuation capabilities. You know, the unfortunate part, once we get all through with that study, we'll just know it for one geographic climate, geological condition, one site area and then we've got the second sight 20 miles away, we're going to check our procedures on. But even there, how many of these case histories do we have to have? Or do we finally say, hey, it's moved this far and set up some criteria?

Unknown Speaker: We're faced with that basic problem that we're not trained in political systems. I think everyone of us runs across that system.

Unknown Speaker: I've been preaching for years, we need a seminar between lawyers and ground-water people. So that we'd learn how to talk the lawyers' language and they in turn would learn how to talk yours.

Dick Pearl: Here it is 11:00–guess we will bring this to a close as all the others are through.

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